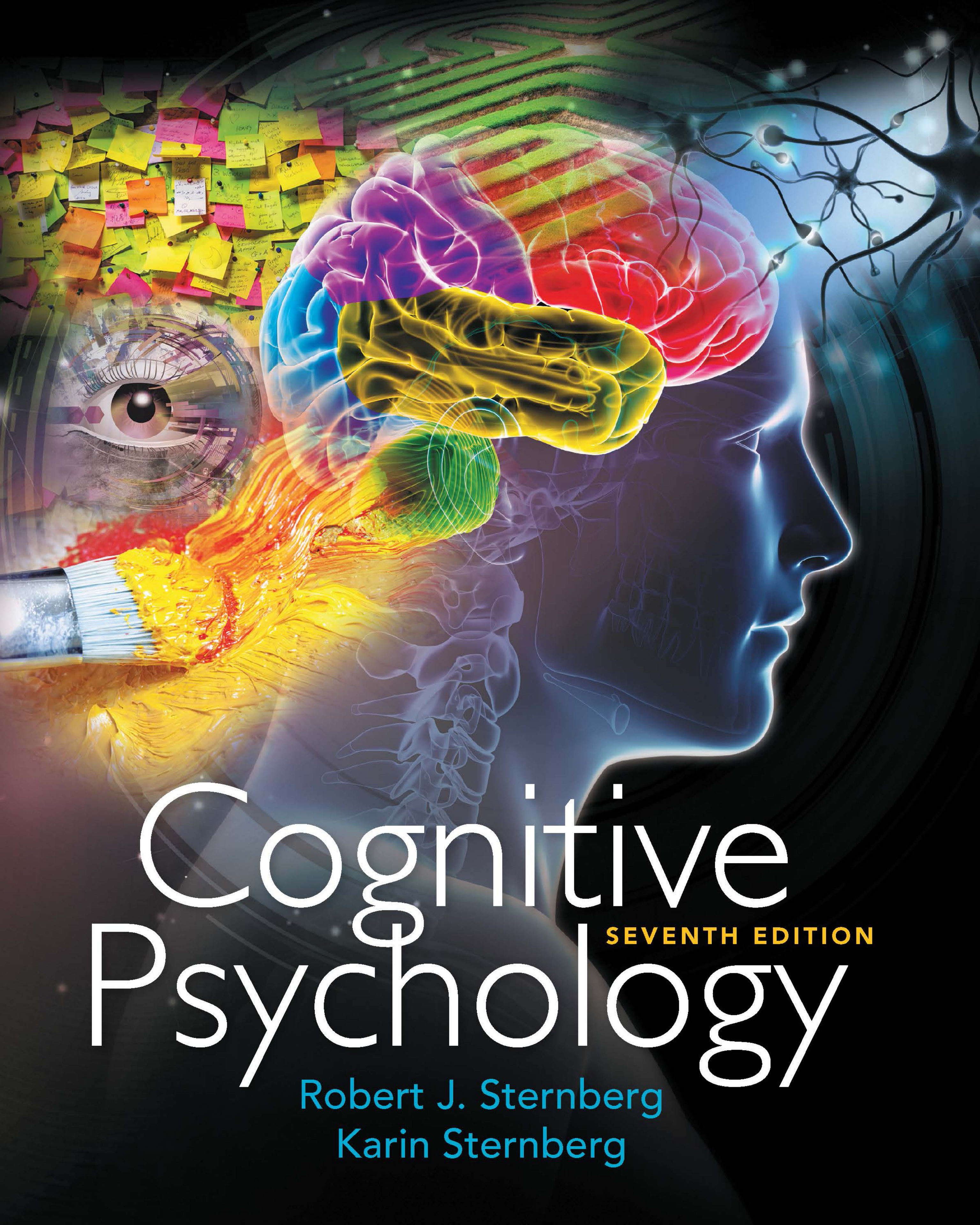

Cognitive Psychology

SEVENTH EDITION

Robert J. Sternberg
Karin Sternberg

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Cognitive Psychology

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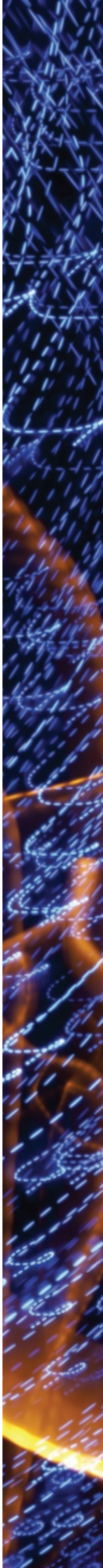

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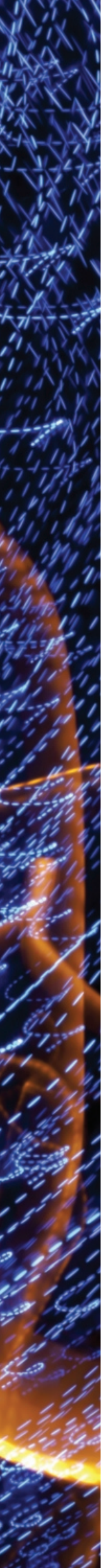

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Preface

To the Instructor

Welcome to the seventh edition of *Cognitive Psychology.* As you have likely noticed, this new edition is now published in four-color print. This greatly enhances the visual appeal of the book and also allows for a whole new level of detail in the images of the book. Most of the images in the book have been replaced or reworked to function even better as learning aids.

A major focus of this revision was the readability and understandability of the text. We have rewritten and modified many sections and have deleted or shortened a number of tables that were long.

In the following sections, we will outline the changes we made to give you an overview of this new edition.

Please also note the section on ancillaries. These materials have been developed to assist you in teaching your cognitive psychology class. A number of resources are available, which are listed in the following sections. We have included additional Internet addresses to the resources interest to students, including virtual tours of a magnetic resonance imaging (MRI) machine, a story about a snowboarder with a traumatic brain injury, and visual description of how to use transcranial magnetic stimulation (TMI) for the treatment of depression.

Goals of this Book

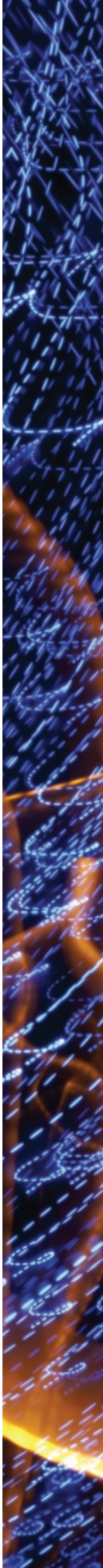
Cognitive psychologists study a wide range of psychological phenomena, such as perception, learning, memory, and thinking. In addition, cognitive psychologists study seemingly less cognitively oriented phenomena, such as emotion and motivation. In fact, almost any topic of psychological interest may be studied from a cognitive perspective. In this textbook, we describe some of the preliminary answers to questions asked by researchers in the main areas of cognitive psychology. The goals of this book are to accomplish the following:

- present the field of cognitive psychology in a comprehensive but engaging manner;
- integrate the presentation of the field under the general banner of human intelligence; and
- interweave throughout the text key themes and key ideas that permeate cognitive psychology.

Mission in Revising the Text

When revising the book, we had a number of goals that guided us through the revision, such as the following:

- make the text more accessible and understandable;
- make cognitive psychology more fascinating and less intimidating;



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- better integrate coverage of cognitive neuroscience in each chapter; and
- develop appealing images, illustrations, and tables.

Major Organizing and Special Pedagogical Features

Several of the features that characterize this textbook are as follows:

- "Believe It or Not" boxes that present incredible and exciting information and facts from the world of cognitive psychology.
- "Practical Applications of Cognitive Psychology" boxes that help students think about applications of cognitive psychology in their own lives.
- "Investigating Cognitive Psychology" boxes that present mini-experiments and tasks that students can complete on their own.
- "Neuroscience and . . . " features included in at least one section per chapter to highlight the presentation of neuroscientific material.
- Concept checks after each major section to help students quickly check their comprehension of the material.

New to the Seventh Edition

Following is an overview of what changes you generally can expect in this edition followed by details of what was changed in each chapter:

- All In-the-Lab boxes were revised and two are completely new: Chapter 7, In the Lab of Doug Medin and Chapter 13, In the Lab of Ian Deary.
- By popular demand, the content on human and artificial intelligence has been removed from the 12 chapters and is now presented again in a separate chapter at the end of the book (Chapter 13, Human Intelligence).
- The book is now printed in four colors.
- Almost all figures and images have been replaced, revised, or adjusted.
- The language has been reviewed and many sections changed or rewritten to facilitate reading comprehension.
- We have added fun new websites to the instructor's manual and companion website to encourage readers to delve deeper into some matters, like stories on traumatic brain damage, a virtual tour of an MRI, and the story of famous neurologic patient H. M.
- The entire text has been rigorously updated.

And finally, here are the detailed changes for each chapter:

Chapter 1

- Rewrote the definition of heuristics and parts of Cognitive Psychology Defined to facilitate comprehension
- Added a figure about the roots of cognitive psychology
- Updated sections on early dialectics in the psychology of cognition, structuralism, associationism, and behaviorism
- Added a new figure on the cycle of research

- Revised the section on experiments to facilitate comprehension
- Edited the Key Themes in Cognitive Psychology section

Chapter 2

- Updated the section on anatomy of the brain: forebrain, midbrain, hindbrain
- Updated section on cerebral cortex and reorganized information on the four lobes to facilitate comprehension
- Updated the sections on studying live nonhuman animals, metabolic imaging, and head injuries
- Added new description of new imaging techniques, including a combination of functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG), functional transcranial Doppler sonography (fTCD), and near-infrared spectroscopy (NIRS)

Chapter 3

- Updated the introduction to clarify the difference between sensation and perception
- Updated the section on the what and where pathways
- Extended the explanation on Selfridge's feature-matching model to facilitate comprehension
- Updated the section on physiology of the eye to facilitate comprehension
- Updated the section on feature matching theories
- Add a new section on CAPTCHAs (Completely Automated Public Turing Test to Tell Computers and Humans Apart) to illustrate template theories
- Updated the sections on geons, viewer-dependent versus object-dependent representation, prosopagnosia, size constancy, shape constancy, and optic ataxia
- Added a new section on recognition of emotions in faces in people with schizophrenia to the section on face perception
- Updated the section on perception in practice

Chapter 4

- Updated the section on the nature of attention and consciousness
- Reorganized and streamlined Table 4.1 on the four main functions of attention
- Updated, shortened, and rewrote the section on search to facilitate comprehension
- Revised the section on selective attention
- Reorganized and revised the section on divided attention
- Added new research about cell phone use or texting and driving to the section on divided attention
- Updated the section on spatial neglect
- Updated the section on attention deficit hyperactivity disorder (ADHD)
- Extended the figure caption for Treisman's and Broadbent's model to facilitate comprehension

Chapter 5

- Restructured Table 5.1 on tasks for measuring memory
- Enhanced coverage of working memory
- Added new sections on alternative models of working memory, neuroscience of working memory, and amnesia research to support distinction between short-term and long-term memory
- Added research on bilingualism to the section on central executive, on how memories are stored, and on formation of new synapses or loss of synapses and brain oscillations

Chapter 6

- Revised discussion of short-term storage
- Revised discussion of Roediger's study on mnemonic devices
- Revised the section on mnemonic devices
- Updated coverage of retrieval from short-term memory
- Added new coverage of connection between encoding specificity and levels of processing approach, as well as brain research to the section on memory consolidation
- Added new research on encoding specificity, reality monitoring and autobiographical memory, sleep and memory consolidation, mnemonic devices, interference theory, and flashbulb memory

Chapter 7

- Redesigned Table 7.1 on propositional representations to facilitate comprehension
- Added a new section to mental maps section
- Added an all-new discussion of neuroscience and functional equivalence
- Updated and expanded the sections on neuroscience and mental rotation, gender differences in mental rotation, and image scanning
- Added a discussion of research on border bias to the section on cognitive maps

Chapter 8

- Clarified the difference between concepts and categories
- Clarified difference between prototypes and exemplars
- Added family resemblance to the section on categorization
- Expanded the explanation of concepts
- Updated the sections on essentialism, network models, schemas and scripts, typicality effect, adaptive control of thought–rational (ACT-R), and parallel distributed processing (PDP)
- Added boundary extension to the section about schemas
- Enhanced the discussion of the differences between connectionist and network representations and their differences with respect to learning

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Chapter 9

- Updated sections on properties of language, number of spoken languages in the world, and examples of newly coined words
- Streamlined and updated sections on basic components of words, speech perception as special, and speech perception as ordinary
- Rewrote parts of the section on transformational grammar to facilitate comprehension
- Added a section on basic approaches to teaching reading
- Reorganized the section on reading
- Added Zwaan's simulation model to representing text in mental models

Chapter 10

- Updated the section on verbal overshadowing effect and bilingualism
- Streamlined and updated sections on Sapir-Whorf hypothesis and linguistic relativity and universals, metaphors, the brain and language, and autism spectrum disorder and language
- Eliminated the section on speech acts

Chapter 11

- Added a new table to better represent the drug problem in the beginning of the chapter and elaborated on the description of the problem
- Added definitions and explanations of key words like initial state, goal state, and obstacles
- Updated the section on problem-solving cycle
- Extended the explanation of and figures on the Tower of Hanoi
- Added a new figure to illustrate the concept of problem space
- Updated the section on types of problems
- Added Duncker's candle problem and two figures illustrating the concept
- Added stereotype threat to the section on mental sets, entrenchment, and fixation
- Added a new section on embodied cognition and problem solving
- Rewrote the transfer of analogies section
- Redesigned Table 11.2 about correspondence between radiation and military problem
- Updated research on analogical problem solving and incubation
- Revised the section on expertise to facilitate comprehension
- Added a new section on expertise and long-term working memory
- Updated the section on creativity

Chapter 12

- Extended and updated information relating to everyday life in sections on availability, satisficing, and anchoring heuristics as well as framing effect
- Extended the explanation in the vaccine example of a framing effect

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- Added a new section on myside bias to the section on biases
- Added a new section on maximizers and satisficers and the effects of their strategies on their well-being
- Updated sections on hindsight bias, gambler's fallacy, and conjunction fallacy
- Extended and updated the section on conditional reasoning in everyday life

Chapter 13

- Added separate chapter to discuss human and artificial intelligence

Ancillaries

As an instructor, you have a multitude of resources available to you to assist you in the teaching of your class. Here is a list of materials you can use:

Instructor's Manual with Test Bank—The Instructor's Manual contains chapter outlines, in-class demonstrations, discussion topics, and suggested websites. The Test Bank includes approximately 75 multiple-choice and 20 short-answer questions per chapter. Each multiple-choice item is labeled with the page reference and level of difficulty.

PowerPoint Presentation Tool—With this one-stop presentation tool, instructors can assemble, edit, and present custom lectures with ease. This tool includes figures and tables from the text, as well as preassembled Microsoft PowerPoint lecture slides. Instructors can use the material or add their own material for a truly customized lecture presentation.

CogLab 5.0—CogLab 5.0 lets students do more than just think about cognition. CogLab 5.0 uses the power of the web to teach concepts using important classic and current experiments that demonstrate how the mind works. Nothing is more powerful for students than seeing the effects of these experiments for themselves. This resources includes such features as simplified student registration, a global database that combines data from students all around the world, between-subject designs that allow for new kinds of experiments, and a quick display of student summaries. Also included are trial-by-trial data, standard deviations, and improved instructions.

When you adopt Sternberg's *Cognitive Psychology*, 7e, you will have access to a rich array of online teaching and learning resources that you won't find anywhere else.

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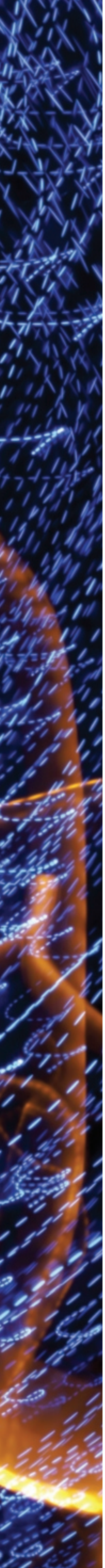

Foreword

To the Student

Why do we remember people whom we met years ago, but sometimes seem to forget what we learned in a course shortly after we take the final exam (or worse, sometimes right before)? How do we manage to carry on a conversation with one person at a party and simultaneously eavesdrop on another more interesting conversation taking place nearby? Why are people so often certain that they are correct in answering a question when in fact they are not? These are just three of the many questions that are addressed by the field of cognitive psychology.

Cognitive psychologists study how people perceive, learn, remember, and think. Although cognitive psychology is a unified field, it draws on many other fields, most notably neuroscience, computer science, linguistics, anthropology, and philosophy. Thus, you will find some of the thinking of all these fields represented in this book. Moreover, cognitive psychology interacts with other fields within psychology, such as cognitive neuroscience, developmental psychology, social psychology, and clinical psychology.

For example, it is difficult to be a clinical psychologist in the twenty-first century without a solid knowledge of developments in cognitive psychology because so much of the thinking in the clinical field draws on cognitive ideas, both in diagnosis and in therapy. Cognitive psychology also has provided a means for psychologists to investigate experimentally some of the exciting ideas that have emerged from clinical theory and practice, such as notions of unconscious thought.

Cognitive psychology will be important to you not only in its own right but also in helping you in all of your work. For example, knowledge of cognitive psychology can help you better understand how best to study for tests, how to read effectively, and how to remember difficult-to-learn material.

Cognitive psychologists study a wide range of psychological phenomena, such as perception, learning, memory, and thinking. In addition, cognitive psychologists study seemingly less cognitively oriented phenomena, such as emotion and motivation. In fact, almost any topic of psychological interest may be studied from a cognitive perspective. In this textbook, we describe some of the preliminary answers to questions asked by researchers in the main areas of cognitive psychology.

- Chapter 1, *Introduction to Cognitive Psychology:* What are the origins of cognitive psychology, and how do people do research in this field?
- Chapter 2, *Cognitive Neuroscience:* What structures and processes of the human brain underlie the structures and processes of human cognition?
- Chapter 3, *Visual Perception:* How does the human mind perceive what the senses receive? How does the human mind perceive forms and patterns?
- Chapter 4, *Attention and Consciousness:* What basic processes of the mind govern how information enters our minds, our awareness, and our high-level processes of information handling?

- Chapter 5, *Memory: Models and Research Methods:* How are different kinds of information (e.g., our experiences related to a traumatic event, the names of U.S. presidents, or the procedure for riding a bicycle) represented in memory?
- Chapter 6, *Memory Processes:* How do we move information into memory, keep it there, and retrieve it from memory when needed?
- Chapter 7, *Mental Images and Propositions:* How do we mentally represent information in our minds? Do we do so in words, in pictures, or in some other form representing meaning? Do we have multiple forms of representation?
- Chapter 8, *The Organization of Knowledge in the Mind:* How do we mentally organize what we know?
- Chapter 9, *Language:* How do we derive and produce meaning through language? How do we acquire language—both our primary language and any additional languages?
- Chapter 10, *Language in Context:* How does our use of language interact with our ways of thinking? How does our social world interact with our use of language?
- Chapter 11, *Problem Solving and Creativity:* How do we solve problems? What processes aid and impede us in reaching solutions to problems? Why are some of us more creative than others? How do we become and remain creative?
- Chapter 12, *Decision Making and Reasoning:* How do we reach important decisions? How do we draw reasonable conclusions from the information we have available? Why and how do we so often make inappropriate decisions and reach inaccurate conclusions?
- Chapter 13, *Human Intelligence:* What is intelligence? How can we measure intelligence? Can intelligence be improved?

To acquire the knowledge outlined in the previous list, we suggest you make use of the following pedagogical features of this book:

1. *Chapter outlines,* beginning each chapter, summarize the main topics covered and thus give you an advance overview of what is to be covered in that chapter.
2. *Opening questions* emphasize the main questions each chapter addresses.
3. *Boldface terms,* indexed at the ends of chapters and defined in the glossary, help you acquire the vocabulary of cognitive psychology.
4. *End-of-chapter summaries* return to the questions at the opening of each chapter and show our current state of knowledge with regard to these questions.
5. *End-of-chapter questions* help you ensure both that you have learned the basic material and that you can think in a variety of ways (factual, analytical, creative, and practical) with this material.
6. *"Investigating Cognitive Psychology" demonstrations,* appearing throughout the chapters, help you see how cognitive psychology can be used to demonstrate various psychological phenomena.
7. *"Practical Applications of Cognitive Psychology" demonstrations* show how you and others can apply cognitive psychology to your everyday lives.
8. *"In the Lab of . . . " boxes* tell you what it really is like to do research in cognitive psychology. Prominent researchers speak in their own words about their research—what research problems excite them most and what they are doing to address these problems.
9. "*Believe It or Not" boxes* present incredible and exciting information and facts from the world of cognitive psychology.

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10. *Key Themes sections,* near the end of each chapter, relate the content of the chapters to the key themes expressed in Chapter 1. These sections will help you see the continuity of the main ideas of cognitive psychology across its various subfields.
11. *CogLab,* an exciting series of laboratory demonstrations in cognitive psychology provided by the publisher of this textbook (Cengage Learning), is available for purchase with this text. You can actively participate in these demonstrations and thereby learn firsthand what it is like to be involved in cognitive-psychological research.

This book contains an overriding theme that unifies all of the diverse topics found in the various chapters: Human cognition has evolved over time as a means of adapting to our environment, and we can call this ability to adapt to the environment *intelligence.* Through intelligence, we cope in an integrated and adaptive way with the many challenges with which the environment presents us.

Although cognitive psychologists disagree about many issues, there is one issue about which almost all of them agree; namely, cognition enables us to successfully adapt to the environments in which we find ourselves. Thus, we need a construct such as that of *human intelligence,* if only to provide a shorthand way of expressing this fundamental unity of adaptive skill. We can see this unity at all levels in the study of cognitive psychology. For example, diverse measures of the psychophysiological functioning of the human brain show correlations with scores on a variety of tests of intelligence. Selective attention, the ability to tune in certain stimuli and tune out others, is also related to intelligence, and it has even been proposed that an intelligent person is one who knows what information to attend to and what information to ignore. Various language and problem-solving skills also are related to intelligence, pretty much without regard to how it is measured. In brief, then, human intelligence can be seen as an entity that unifies and provides direction to the workings of the human cognitive system.

We hope you enjoy this book, and we hope you see why we are enthusiastic about cognitive psychology and proud to be cognitive psychologists.

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Dr. Sternberg has served as president of the APA, the Eastern Psychological Association, and the Federation of Associations in Behavioral and Brain Sciences. He currently is editor of *Perspectives on Psychological Science* and previously was editor of the *Psychological Bulletin* and the *APA Review of Books: Contemporary Psychology.* He is a member of the American Academy of Arts and Sciences, the National Academy of Education, and the Society of Experimental Psychologists. He is a fellow of APA, Association for Psychological Science, and American Association for the Advancement of Science. He was the director of the Center for the Psychology of Abilities, Competencies, and Expertise at Yale University.

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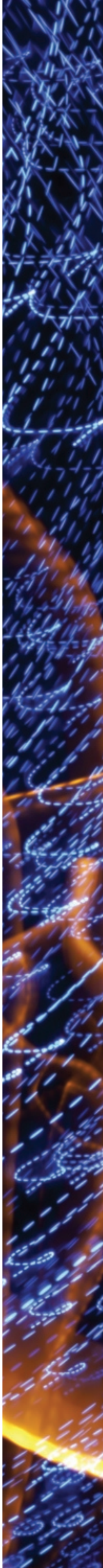
1

Introduction to Cognitive Psychology

CHAPTER OUTLINE

- **Cognitive Psychology Defined**
- **Philosophical Origins of Psychology: Rationalism versus Empiricism**
- **Psychological Origins of Cognitive Psychology**
  - Early Dialectics in the Psychology of Cognition
    - Understanding the Structure of the Mind: Structuralism
    - Understanding the Processes of the Mind: Functionalism
    - An Integrative Synthesis: Associationism
  - It's Only What You Can See That Counts: From Associationism to Behaviorism
    - Proponents of Behaviorism
    - Criticisms of Behaviorism
    - Behaviorists Daring to Peek into the Black Box
  - The Whole Is More Than the Sum of Its Parts: Gestalt Psychology
- **Emergence of Cognitive Psychology**
  - Early Role of Cognitive Neuroscience
  - Add a Dash of Technology: Engineering, Computation, and Applied Cognitive Psychology
- **Research Methods in Cognitive Psychology**
  - Goals of Research
  - Distinctive Research Methods
    - Experiments on Human Behavior
    - Neuroscientific Research
    - Self-Reports, Case Studies, and Naturalistic Observation
    - Computer Simulations and Artificial Intelligence
    - Putting It All Together
- **Fundamental Ideas in Cognitive Psychology**
- **Key Themes in Cognitive Psychology**
- **Summary**
- **Thinking about Thinking: Analytical, Creative, and Practical Questions**
- **Key Terms**



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Here are some of the questions we will explore in this chapter:

1. What is cognitive psychology?
2. How did psychology develop as a science?
3. How did cognitive psychology develop from psychology?
4. How have other disciplines contributed to the development of theory and research in cognitive psychology?
5. What methods do cognitive psychologists use to study how people think?
6. What are the current issues and various fields of study within cognitive psychology?

BELIEVE IT OR NOT

Now You See It, Now You Don't!

Note: Do not read on before you have watched the video.

Cognitive psychology yields all kinds of surprising findings. Dan Simons of the University of Illinois is a master of surprises (see Simons, 2007; Simons & Ambinder, 2005; Simons & Rensink, 2005). Try it out yourself! Watch the following videos and see if you have any comments on them.

viscog.beckman.illinois.edu/flashmovie/23.php

Did you notice that the person who answers the phone is not the same as the one who was at the desk? Note that they are wearing distinctively different clothing. You have just seen an example of change blindness—our occasional inability to recognize changes. You will learn more about this concept in Chapter 3.

Now view the following video. Your task will be to count the number of times that students in *white shirts* pass the basketball. You must not count passes by students wearing black shirts:

viscog.beckman.illinois.edu/flashmovie/15.php

Well, it doesn't really matter how many passes there were. Did you notice the person in the gorilla outfit walk across the video as the students were throwing the balls? Most people don't notice. This video demonstrates a phenomenon called *inattentional blindness*. You will learn more about this concept in Chapter 4. Throughout this book, we will explore these and many other phenomena.

Think back to the last time you went to a party or social gathering. There were probably tens and maybe hundreds of students in a relatively small room. Maybe music played in the background, and you could hear chatter all around. Yet, when you talked to your friends, you were able to figure out and even concentrate on what they said, filtering out all the other conversations that were going on in the background. Suddenly, however, your attention might have shifted because you heard someone in another conversation nearby mention your name. What processes would have been at work in this situation? How were you able to filter out irrelevant voices in your mind and focus your attention on just one of the many voices you heard? And why did you notice your name being mentioned, even though you did not purposefully listen to the conversations around you? Our ability to focus on one out of many voices is one of the most striking phenomena in cognitive psychology, and this phenomenon is known as the "cocktail party effect."

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When you are at a party, you are usually able to filter out many irrelevant voice streams to concentrate on the conversation you are leading. However, you will likely notice somebody saying your name in another conversation even if you were not listening intently to that conversation.

Cognitive processes are continuously taking place in your mind and in the minds of the people around you. Whether you pay attention to a conversation, estimate the speed of an approaching car when crossing the street, or memorize information for a test at school, you are perceiving information, processing it, and remembering or thinking about it. This book is about those cognitive processes that are often hidden in plain sight and that we take for granted because they seem so automatic to us. This chapter will introduce you to some of the people who helped form the field of cognitive psychology and make it what it is today. The chapter also will discuss methods used in cognitive-psychological research.

Cognitive Psychology Defined

What will you study in a textbook about cognitive psychology?

Cognitive psychology is the study of how people perceive, learn, remember, and think about information. A cognitive psychologist might study how people perceive various shapes, why they remember some facts but forget others, or how they learn language. Consider some examples:

- Why do objects look farther away on foggy days than they really are?
- Why do many people remember a particular experience (e.g., a very happy moment or an embarrassment during childhood), yet they forget the names of people whom they have known for many years?
- Why are many people more afraid of traveling in planes than in automobiles?

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- Why do you often easily remember people you met in your childhood but not people you met a week ago?
- Why do marketing executives in large companies spend so much company money on advertisements?

These are some of the kinds of questions that we can answer through the study of cognitive psychology.

Consider just the last of these questions: Why does Apple, for example, spend so much money on advertisements for its iPhone? After all, how many people remember the functional details of the iPhone, or how those functions distinguish it from the functions of other phones? One reason Apple spends so much is because of the *availability heuristic*, which you will study in Chapter 12. **Heuristics** are mental shortcuts we use to process information. When we think about an issue and certain examples immediately come to mind, we are using the "availability heuristic" (Tversky & Kahneman, 1973). For example, when we are thinking about buying a new cell phone, we are much more likely to buy a brand and model of a phone that is familiar. Similarly, Microsoft paid a lot of money to market its rollout of Windows 8.1 to make the product cognitively available to potential customers and thus increase the chances that the potential customers would become actual ones. The bottom line is that understanding cognitive psychology can help us understand much of what goes on in our everyday lives.

Why study the history of cognitive psychology? If we know where we came from, we may better understand where we are heading. In addition, we can learn from past mistakes. For example, there are numerous newspaper stories about how one educational program or another has resulted in particular gains in student achievement. It is relatively rare, however, to read that a control group has been used. A control group might tell us about the achievement of students who did not have that educational program or who were in an alternative program. It may be that these students also showed a gain. We need to compare the students in the experimental group to those in the control group to determine whether the gain of the students in the experimental group was greater than the gain of those in the control group. We can learn from the history of our field that it is important to include control groups, but not everyone learns this fact.

The fundamental questions in cognitive psychology remain the same, but the ways of addressing these issues have changed. Ultimately, cognitive psychologists hope to learn how people think by studying how people have thoughts about thinking.

The approaches and ways scientists use to study issues in cognitive psychology change over time. These changes often are the result of a dialectic. A **dialectic** is a developmental process whereby ideas evolve over time through a back-and-forth exchange of ideas; in a way, it is like a discussion spread out over an extended period of time. The dialectical process looks like this:

1. **A thesis is proposed.** A *thesis* is a statement of belief. For example, some people believe that human nature (i.e., the effects of our genes) influences many aspects of human behavior (e.g., intelligence or personality; Sternberg, 1999). After a while, however, certain individuals notice apparent flaws in the thesis.
2. **An antithesis emerges.** Eventually, or perhaps even quite soon, an antithesis emerges. An *antithesis* is a statement that counters a thesis. For example, an alternative view is that our environment (whose effects are called "nurture") almost entirely determines many aspects of human behavior.
3. **A synthesis integrates the viewpoints.** Sooner or later, the debate between the thesis and the antithesis leads to a synthesis, which integrates the most credible features of each of two (or more) views. For example, in the debate over nature

versus nurture, the interaction between our innate (inborn) nature and environmental nurture may govern human nature.

The dialectic is important because we may be tempted to think that if one view is right, another seemingly contrasting view must be wrong. For example, in the field of **intelligence**, many tend to believe that intelligence is either all or mostly genetically determined, or all or mostly environmentally determined. A similar debate has raged in the field of language acquisition. It is better to examine such issues as different forces that interact with and influence each other than to view these issues as either–or questions. Indeed, the most widely accepted current contention is that the "nature or nurture" view is incomplete. Nature and nurture work together in our development.

Nurture can work in different ways in different cultures. Some cultures, especially Asian cultures, tend to be more dialectical in their thinking, whereas other cultures, such as European and North American ones, tend to be more linear (Nisbett, 2003). In other words, Asians are more likely to be tolerant of holding beliefs that are contradictory, expecting that at some point a resolution will resolve the conflict in their beliefs. Europeans and Americans expect their belief systems to be consistent with each other.

Similarly, people from Asian cultures tend to take a different viewpoint than Westerners when seeing or hearing something new (e.g., a movie of fish in an ocean; Nisbett & Masuda, 2003). So if people see a movie of fish swimming around in the ocean, Europeans or Americans will tend to pay more attention to the fish, and Asians may attend more to the surround of the ocean in which the fish are swimming. That is, people from Western cultures generally tend to process objects independently of the context, whereas people from many Eastern cultures look at objects embedded in their surrounding context (Nisbett & Miyamoto, 2005). Asians may emphasize the context more than the objects embedded in those contexts. The evidence suggests that culture influences many cognitive processes, including intelligence (Lehman, Chiu, & Schaller, 2004).

If a synthesis advances our understanding of a subject, it then serves as a new thesis. A new antithesis then follows it, then a new synthesis, and so on. You will see in this chapter that psychology also evolved as a result of dialectics: Psychologists had ideas about how the mind works and pursued their line of research; then other psychologists pointed out weaknesses and developed alternatives as a reaction to the earlier ideas. Eventually, characteristics of the different approaches are often integrated into a newer and more encompassing approach.

Philosophical Origins of Psychology: Rationalism versus Empiricism

Where and when did the study of cognitive psychology begin? Historians of psychology usually trace the earliest roots of psychology to two approaches to understanding the human mind:

- *philosophy,* which seeks to understand the general nature of many aspects of the world, in part through *introspection*, the examination of inner ideas and experiences (from *intro*, "inward, within," and *spect*, "look")
- *physiology,* which seeks a scientific study of life-sustaining functions in living matter, primarily through *empirical* (observation based) methods

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■ **Figure 1.1 Rationalism and Empiricism.** (a) According to the rationalist, the only route to truth is reasoned contemplation; (b) according to the empiricist, the only route to truth is meticulous observation. Cognitive psychology, like other sciences, depends on the work of both rationalists and empiricists.

Two Greek philosophers, Plato (ca. 428–348 B.C.) and his student Aristotle (384–322 B.C.), have profoundly affected modern thinking in psychology and many other fields. Plato and Aristotle disagreed regarding how to investigate ideas.

Plato was a rationalist. A **rationalist** believes that the route to knowledge is through thinking and logical analysis. That is, a rationalist does not need any experiments to develop new knowledge. A rationalist who is interested in cognitive processes would appeal to reason as a source of knowledge or justification.

In contrast, Aristotle (a naturalist and biologist as well as a philosopher) was an empiricist. An **empiricist** believes that we acquire knowledge via empirical evidence—that is, we obtain evidence through experience and observation (Figure 1.1 ■). To explore how the human mind works, empiricists would design experiments and conduct studies in which they could observe the behavior and processes of interest to them. Empiricism therefore leads directly to empirical investigations of psychology. Later in this chapter, we will discuss the empirical research methods that are used in cognitive psychology.

In contrast, rationalism is important in theory development. Rationalist theories without any connection to observations gained through empiricist methods may not be valid; but mountains of observational data without an organizing theoretical framework may not be meaningful. We might see the rationalist view of the world as a thesis and the empirical view as an antithesis. Most twenty-first-century psychologists seek a synthesis of the two. They base empirical observations on theory to explain what they have observed in their experiments. In turn, they use these observations to revise their theories when they find that the theories cannot account for their real-world observations.

The contrasting ideas of rationalism and empiricism became prominent with the French rationalist René Descartes (1596–1650) and the British empiricist John Locke (1632–1704). Descartes viewed the introspective, reflective method as being superior to empirical methods for finding truth. The famous expression *cogito, ergo sum* (I think, therefore I am) stems from Descartes. He maintained that the only proof of his existence is that he was thinking and doubting. Descartes felt that one could not rely on one's senses because those very senses have often proven to be deceptive (e.g., think of optical illusions). Locke, in contrast, had more enthusiasm for empirical observation (Leahey, 2003). Locke believed that humans are born without knowledge and therefore must seek knowledge through empirical observation. Locke's term for this view was *tabula rasa* (meaning "blank slate" in Latin). The idea is that life and experience "write" knowledge

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on us. For Locke, then, the study of learning was the key to understanding the human mind. He believed that there are no innate ideas.

In the eighteenth century, German philosopher Immanuel Kant (1724–1804) synthesized the views of Descartes and Locke, arguing that both rationalism and empiricism have their place. Both must work together in the quest for truth. Most twenty-first-century psychologists accept Kant's synthesis. The roots of cognitive psychology discussed here and in the next sections are summarized in Figure 1.2 ■.

Psychological Origins of Cognitive Psychology

Cognitive psychology has roots in many different ideas and approaches (see, e.g., King, Woody, & Viney, 2013; Leahey, 2012). The approaches that will be examined include early approaches such as structuralism and functionalism, followed by a discussion of associationism, behaviorism, and Gestalt psychology.

Early Dialectics in the Psychology of Cognition

Psychology only recently emerged as a new and independent field of study (Hergenhahn & Henley, 2013). It developed in a dialectical way. Typically, an approach to studying the mind would be developed; people then would use it to explore the human psyche. At some point, however, researchers would find that the approach they used had some weaknesses, or they would disagree with some fundamental assumptions of that approach. They then would develop a new approach. Future approaches might integrate the best features of past approaches or reject some or even most of those characteristics. In the following section, we will explore some of the ways of thinking early psychologists employed and trace the development of psychology through the various schools of thinking. Take note that there is not, and never has been, just one right approach to studying cognitive psychology. Rather, researchers have used one or more approaches as bases for their work but also appreciated the value of other approaches.

Archives of the History of American Psychology—University of Akron

Wilhelm Wundt was no great success in school, failing time and again and frequently finding himself subject to the ridicule of others. However, Wundt later showed that school performance does not always predict career success because he is considered to be among the most influential psychologists of all time.

Understanding the Structure of the Mind: Structuralism

An early dialectic in the history of psychology is that between structuralism and functionalism (Kardas, 2013; Leahey, 2012; Morawski, 2000). Structuralism was the first major school of thought in psychology. **Structuralism** seeks to understand the structure (configuration of elements) of the mind and its perceptions by analyzing those perceptions into their constituent components (affection, attention, memory, and sensation).

Consider, for example, the perception of a flower. Structuralists would analyze this perception in terms of its colors, geometric forms, size relations, and so on. In terms of the human mind, structuralists sought to deconstruct the mind into its elementary components; they were also interested in how those elementary components work together to create the mind (Benjamin, 2014).

Wilhelm Wundt (1832–1920) was a German psychologist whose ideas contributed to the development of structuralism (Wertheimer, 2011). Wundt is often viewed as the founder of structuralism in psychology (Structuralism, 2009). Wundt used a variety of methods in his research. One of these methods was introspection. **Introspection** is the conscious observation of one's own thinking processes. The aim of introspection is to look at the elementary components of an object or process.

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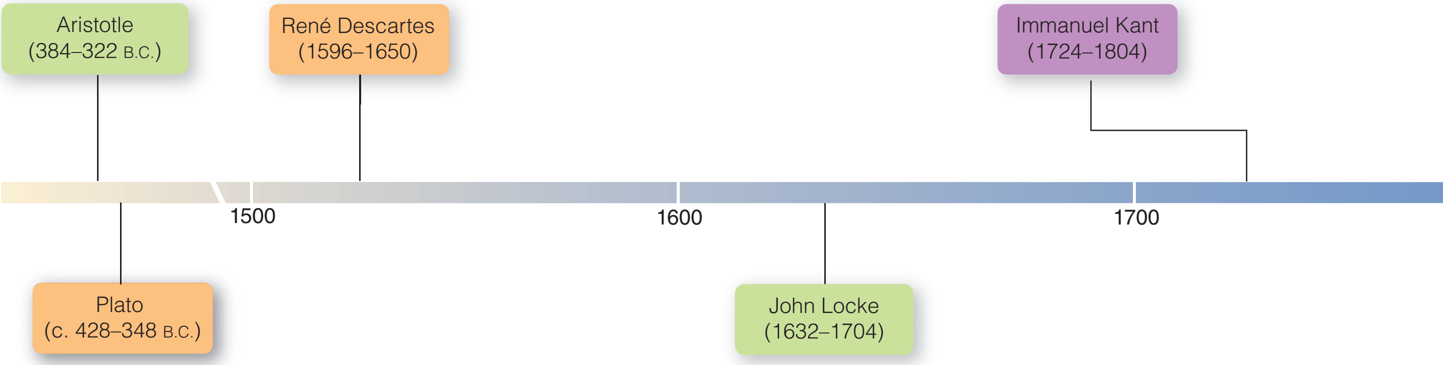
Methods To Gain Knowledge	How Knowledge Is Gained
🟧 **Rationalism**	Through reflective thinking and logical analysis
🟩 **Empiricism**	Through observation
🟪 **Synthesis**	Through the use of observation as well as thinking and logical analysis



Approaches to Studying the Mind	Methods Used	What Is Studied
🟦 **Structuralism**	Introspection	Content/structure of the mind
🟫 **Functionalism**	Various; depends on question asked	Processes of how the mind works
🟩 **Pragmatism**	Various	Research that can be applied to the real world
🟨 **Synthesis:** Associationism	Experiments*:* Ebbinghaus used himself as a subject; Thorndike used cats as well as humans.	How learning takes place by associating things with each other
🟦 **Behaviorism** (extreme form of associationism)	Use of animals in research in addition to humans Quantitative analysis	Relations between observable behavior and environmental events/stimuli
🟪 **Gestalt psychology**	Introspection, experiments	Psychological phenomena studied as organized wholes
🟥 **Synthesis:** Cognitivism	Experiments, computer simulation, protocol analysis	Understand behavior through the ways people think

■ **Figure 1.2 Roots of Cognitive Psychology.**

The introduction of introspection as an experimental method was an important change in the field because the main emphasis in the study of the mind shifted from a rationalist approach to the empiricist approach of observing behavior to draw conclusions about the subject of study. In experiments involving introspection, individuals reported on their thoughts as they were working on a given task (Goodwin, 2011). Researchers interested in problem solving could ask their participants to think aloud while they were working on a puzzle so the researchers could gain insight into the thoughts that go on in the participants' minds. In introspection, then, we can analyze our own perceptions.

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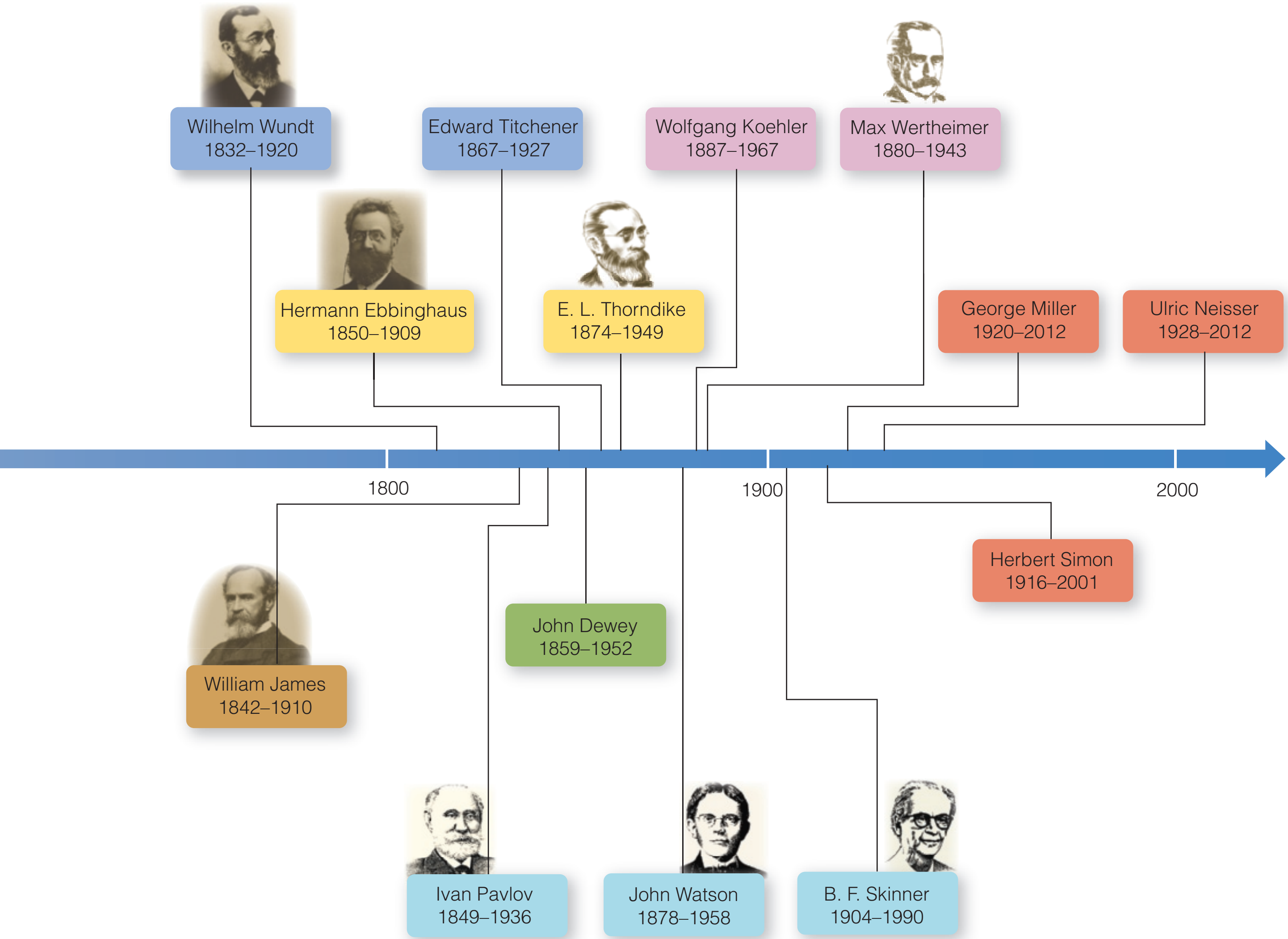
Wilhelm Wundt
1832–1920
Edward Titchener
1867–1927
Wolfgang Koehler
1887–1967
Max Wertheimer
1880–1943
Hermann Ebbinghaus
1850–1909
E. L. Thorndike
1874–1949
George Miller
1920–2012
Ulric Neisser
1928–2012
1800
1900
2000
Herbert Simon
1916–2001
John Dewey
1859–1952
William James
1842–1910
Ivan Pavlov
1849–1936
John Watson
1878–1958
B. F. Skinner
1904–1990

The method of introspection has some challenges associated with it. First, people may not always be able to say exactly what goes through their mind or may not be able to put it into adequate words. Second, what they say may not be accurate. Third, the fact that people are asked to pay attention to their thoughts or to speak out loud while they are working on a task may itself alter the processes that are going on.

Wundt had many followers. One was an American student, Edward Titchener (1867–1927). Titchener (1910) is sometimes viewed as the first full-fledged structuralist. In any case, he certainly helped bring structuralism to the United States. His experiments relied solely on the use of introspection, exploring psychology from the vantage point of the experiencing individual. Other early psychologists criticized both the method (introspection) and the focus (elementary structures of sensation) of structuralism. These critiques gave rise to a new movement—functionalism.

Understanding the Processes of the Mind: Functionalism

Functionalism was developed as an alternative to structuralism, and suggested that psychologists should focus on the *processes* of thought rather than on its contents. **Functionalism** seeks to understand what people *do* and *why* they do it. This principal

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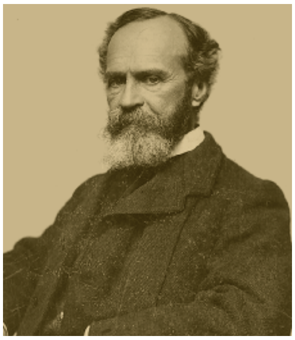

Archives of the History of American Psychology—University of Akron

Many cognitive psychologists regard William James, a physician, philosopher, and brother of author Henry James, as among the greatest psychologists ever, although James himself seems to have rejected psychology later in his life.

question about processes was in contrast to that of the structuralists, who had asked what the elementary contents (structures) of the human mind are. Functionalists held that the key to understanding the human mind and behavior was to study the processes of how and why the mind works as it does, rather than to study the structural contents and elements of the mind. They were particularly interested in the practical applications of their research.

Functionalists were unified by the kinds of questions they asked but not necessarily by the answers they found or by the methods they used for finding those answers. Because functionalists believed in using whichever methods best answered a given researcher's questions, it seems natural for functionalism to have led to pragmatism. **Pragmatists** believe that knowledge is validated by its usefulness: What can you *do* with it? Pragmatists are concerned not only with knowing what people do; they also want to know what we can do with our knowledge of what people do. For example, pragmatists believe in the importance of the psychology of learning and memory. Why? Because it can help us improve children's performance in school. It can also help us learn to remember the names of people we meet.

A leader in guiding functionalism toward pragmatism was William James (1842–1910). His chief functional contribution to the field of psychology was a single book: his landmark *Principles of Psychology* (1890/1970). Even more than a century later, cognitive psychologists frequently point to the writings of James in discussions of core topics in the field, such as attention, consciousness, and perception. John Dewey (1859–1952) was another early pragmatist who profoundly influenced contemporary thinking in cognitive psychology. Dewey is remembered primarily for his pragmatic approach to thinking and schooling.

Although functionalists were interested in how people learn, they did not really specify a mechanism by which learning takes place. This task was taken up by another group, associationists.

An Integrative Synthesis: Associationism

Associationism, like functionalism, was more of an influential way of thinking than a rigid school of psychology. **Associationism** examines how elements of the mind, such as events or ideas, can become associated with one another in the mind to result in a form of learning. For example, associations may result from

- *contiguity* (associating things that tend to occur together at about the same time);
- *similarity* (associating things with similar features or properties); or

practical applications of **COGNITIVE PSYCHOLOGY**

Pragmatism

Take a moment right now to put the idea of pragmatism into use. How can you make the information you are learning in this course more useful to you?

1. This chapter begins and ends with the same questions to make the information more coherent and useful. Come up with your own questions and organize your notes in the form of answers to your questions.
2. Connect this chapter's material to your other courses and activities. For example, if asked to explain a new app to a friend, a good way to start would be to ask your friend, "Do you have any questions?" That way, the information you provide is more directly useful to your friend rather than forcing your friend to search for the information by listening to a long, one-sided lecture.

How can pragmatism be useful in your life (other than in your college coursework)?

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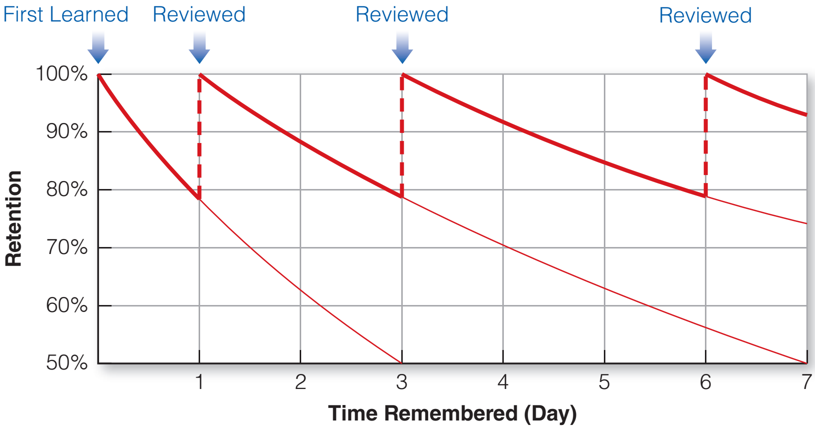

■ **Figure 1.3** **Ebbinghaus Forgetting Curve.** The Ebbinghaus Forgetting Curve shows that the first few repetitions result in a steep learning curve. Later repetitions result in a slower increase of remembered words.

- *contrast* (associating things that show polarities, such as hot/cold, light/dark, day/night).

Bettmann/CORBIS

German experimental psychologist Hermann Ebbinghaus.

In the late 1800s, Hermann Ebbinghaus (1850–1909) was the first experimenter to apply associationist principles systematically (Benjamin, 2014). Specifically, Ebbinghaus studied his own mental processes. He made up lists of nonsense syllables that consisted of a consonant and a vowel followed by another consonant (e.g., zax). He then took careful note of how long it took him to memorize those lists. He counted his errors and recorded his response times. Through his self-observations, Ebbinghaus studied how people learn and remember material through *rehearsal*, the conscious repetition of material to be learned (Figure 1.3 ■). Among other things, he found that frequent repetition can fix mental associations more firmly in memory. Thus, repetition aids in learning (see Chapter 6).

Another influential associationist, Edward Lee Thorndike (1874–1949), held that the role of "satisfaction" is the key to forming associations. Thorndike termed this principle the *law of effect* (1905): A stimulus will tend to produce a certain response over time if an organism is rewarded for that response. Thorndike believed that an organism learns to respond in a given way (the *effect*) in a given situation if it is rewarded repeatedly for doing so (the *satisfaction*, which serves as a stimulus to future actions). Thus, a child given treats for solving arithmetic problems learns to solve arithmetic problems accurately because the child forms associations between valid solutions and treats. These ideas were the predecessors of the development of behaviorism.

It's Only What You Can See That Counts: From Associationism to Behaviorism

Other researchers who were contemporaries of Thorndike used animal experiments to probe stimulus–response relationships in ways that differed from those of Thorndike and his fellow associationists. These researchers straddled the line between associationism and the emerging field of behaviorism. **Behaviorism** focuses only on the relation between observable behavior and environmental events or stimuli. The idea was to make physical whatever others might have called "mental" (Lycan, 2003). Some of these

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researchers, such as Thorndike and other associationists, studied responses that were voluntary (although perhaps lacking any conscious thought, as in Thorndike's work). Other researchers studied responses that were involuntarily triggered in response to what appear to be unrelated external events.

In Russia, Nobel Prize–winning physiologist Ivan Pavlov (1849–1936) studied involuntary learning behavior of this sort. He began with the observation that dogs salivated in response to the sight of the lab technician who fed them. This response occurred before the dogs even saw whether the technician had food. To Pavlov, this response indicated a form of learning (classically conditioned learning), over which the dogs had no conscious control. In the dogs' minds, some type of involuntary learning linked the technician to the food (Pavlov, 1955). Pavlov's landmark work paved the way for the development of behaviorism. His ideas were made known in the United States especially through the work of John B. Watson (see next section). Classical conditioning involves more than just an association based on temporal contiguity (e.g., the food and the conditioned stimulus occurring at about the same time; Ginns, 2006; Rescorla, 1967). Effective conditioning requires *contingency* (e.g., the presentation of food being contingent [i.e., dependent] on the presentation of the conditioned stimulus; Rescorla & Wagner, 1972; Wagner & Rescorla, 1972). Contingencies in the form of reward and punishment are still used in the twenty-first century, for example, in the treatment of substance abuse (Cameron & Ritter, 2007).

Behaviorism may be considered an extreme version of associationism. It focuses entirely on the association between the environment and an observable behavior. According to strict, extreme ("radical") behaviorists, any hypotheses about internal thoughts and ways of thinking are nothing more than speculation (Benjamin, 2014). Radical behaviorists have tried to influence the way people handle problems in everyday life, from child-rearing, to schooling, even to close personal relationships (Benjamin & Baker, 2014).

Proponents of Behaviorism

The "father" of radical behaviorism is John Watson (1878–1958). Watson had no use for internal mental contents (thoughts) or mechanisms. He believed that psychologists should concentrate only on the study of observable behavior (Doyle, 2000). He dismissed thinking as nothing more than subvocalized speech. Behaviorism also differed from previous movements in psychology by shifting the emphasis of experimental research from human to animal participants. Historically, much behaviorist work has been conducted (and still is) with laboratory animals, such as rats or pigeons, because these animals allow for much greater behavioral control of relationships between the environment and the behavior emitted in reaction to it (although behaviorists also have conducted experiments with humans). One problem with using nonhuman animals, however, is determining whether the research can be *generalized* to humans (i.e., applied more generally to humans instead of just to the kinds of nonhuman animals that were studied).

B. F. Skinner (1904–1990), a radical behaviorist, believed that virtually all forms of human behavior, not just learning, could be explained by reactions to the environment. Skinner conducted research primarily with nonhuman animals. He rejected mental mechanisms. He believed instead that *operant conditioning*—involving the strengthening or weakening of behavior, contingent on the presence or absence of reinforcement (rewards) or punishments—could explain all forms of human behavior. Skinner applied his experimental analysis of behavior to many psychological phenomena, such as learning, language acquisition, and problem solving. Largely because of Skinner's towering presence, behaviorism dominated the discipline of psychology for several decades.

Criticisms of Behaviorism

Behaviorism was challenged on many fronts such as language acquisition, production, and comprehension. First, although it seemed to work well to account for certain kinds of learning, behaviorism did not account as well for complex mental activities, such as language learning and problem solving. Second, more than understanding people's behavior, some psychologists wanted to know what went on inside the head. Third, using the techniques of behaviorism to study nonhuman animals was often easier than studying human ones. Nonetheless, behaviorism continues as a school of psychology, although not one that is particularly sympathetic to the cognitive approach, which involves metaphorically and sometimes literally peering inside people's heads to understand how they learn, remember, think, and reason. Other criticisms emerged as well, as discussed in the next section.

Behaviorists Daring to Peek into the Black Box

Some psychologists rejected radical behaviorism. They were curious about the contents of the mysterious *black box*. Behaviorists regarded the mind as a black box that is best understood in terms of its input and output, but whose internal processes cannot be accurately described because they are not observable. For example, a critic, Edward Tolman (1886–1959), thought that understanding behavior required taking into account the purpose of, and the plan for, the behavior. Tolman (1932) believed that all behavior is directed toward a goal. For example, the goal of a rat in a maze may be to try to find food in that maze. Tolman is sometimes viewed as a forefather of modern cognitive psychology.

BELIEVE IT OR NOT | Scientific Progress!?

The progress of science can take unbelievable turns at times. From the early 1930s to the 1960s, lobotomies were a popular and accepted means of treating mental disorders. A lobotomy involves cutting the connections between the frontal lobes of the brain and the thalamus. Psychiatrist Walter Freeman developed a particular kind of lobotomy in 1946—the transorbital or "ice pick" lobotomy. In this procedure, he inserted an ice pick–like instrument through the orbit of the eyes into the frontal lobes where it was moved back and forth. The patient had been previously rendered unconscious by means of a strong electrical shock. By the late 1950s, tens of thousands of Americans had been subjected to this "psychosurgery." According to some accounts, people felt reduced tension and anxiety after the surgery; however, many people died or were permanently incapacitated after the lobotomy. One famous lobotomy patient included John F. Kennedy's sister Rosemary. Unbelievably, lobotomies were even performed on patients who were not aware they were receiving the surgery. Howard Dully was lobotomized at age 12 years old and did not find out about the procedure until much later in life

(Helmes & Velamoor, 2009; MSNBC, 2005).

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In a lobotomy, connections between the frontal lobes of the brain and the thalamus are severed.

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Bandura (1977) noted that learning appears to result not merely from direct rewards for behavior, but it also can be social, resulting from observations of the rewards or punishments given to others. Learning through observation is well documented and can be seen in humans, monkeys, dogs, birds, and even fish (Brown & Laland, 2001; Laland, 2004). In humans, this ability spans all ages; it is observed in both infants and adults (MejiaArauz, Rogoff, & Paradise, 2005). This view emphasizes how we observe and model our own behavior after the behavior of others. We learn by example. This consideration of social learning opens the way to considering what is happening inside the mind of the individual.

The Whole Is More Than the Sum of Its Parts: Gestalt Psychology

Of the many critics of behaviorism, Gestalt psychologists may have been among the most avid. **Gestalt psychology** states that we best understand psychological phenomena when we view them as organized, structured wholes. According to this view, we cannot fully understand behavior when we only break phenomena down into smaller parts. For example, behaviorists tended to study problem solving by looking for subvocal processing (when people murmur to themselves). They were looking for the observable behavior through which problem solving can be understood. Gestaltists, in contrast, studied insight, to understand the unobservable mental event by which someone goes from having no idea about how to solve a problem to understanding it fully in what seems a mere moment of time.

The maxim “the whole is more than the sum of its parts” aptly sums up the Gestalt perspective. To understand the perception of a flower, for example, we would have to take into account the whole of the experience. We could not understand such a perception merely in terms of a description of forms, colors, sizes, and so on. Similarly, as noted in the previous paragraph, we could not understand problem solving merely by looking at minute elements of observable behavior (Köhler, 1927, 1940; Wertheimer, 1945/1959). We will have a closer look at Gestalt principles in Chapter 3.

Emergence of Cognitive Psychology

In the early 1950s, a movement called the “cognitive revolution” took place in response to behaviorism. **Cognitivism** is the belief that most human behavior explains how people think. It rejects the behavioristic notion that psychologists should avoid studying mental processes just because they are unobservable. Cognitivism is, in part, a synthesis of earlier forms of analysis, such as behaviorism and Gestaltism. Like behaviorism, it adopts precise quantitative analysis to study how people learn and think; like Gestaltism, it emphasizes internal mental processes.

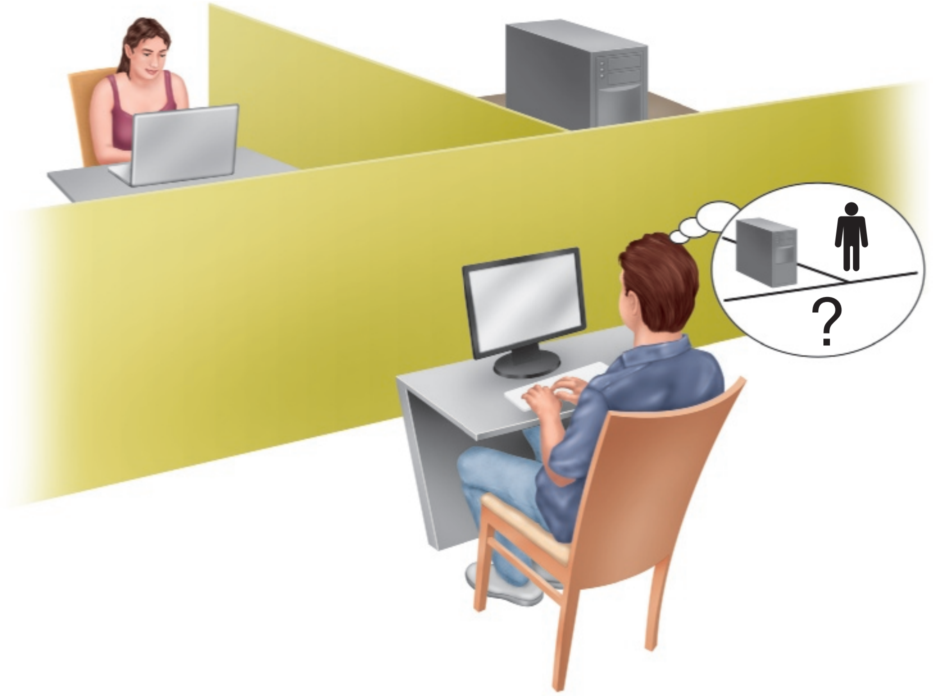
Early Role of Cognitive Neuroscience

Ironically, one of Watson’s former students, Karl Spencer Lashley (1890–1958), brashly challenged the behaviorist view that the human brain is a passive organ merely responding to environmental contingencies outside the individual (Gardner, 1985). Instead, Lashley considered the brain to be an active, dynamic organizer of behavior. Lashley sought to understand how the macro-organization of the human brain made possible complex, planned activities such as musical performance, game playing, and using language. None of these activities were, in his view, readily explicable in terms of simple conditioning.

In the same vein, but at a different level of analysis, Donald Hebb (1948) proposed the concept of cell assemblies as the basis for learning in the brain. Cell assemblies are coordinated neural structures that develop through frequent stimulation. They develop over time as the ability of one neuron (nerve cell) to stimulate firing in a connected neuron increases. Behaviorists did not jump at the opportunity to agree with theorists such as Lashley and Hebb. In fact, Skinner (1957) wrote an entire book describing how language acquisition and usage could be explained purely in terms of environmental contingencies. This work stretched Skinner's framework too far, leaving Skinner open to attack. An attack was indeed forthcoming. Linguist Noam Chomsky (1959) wrote a scathing review of Skinner's ideas. In his article, Chomsky stressed both the biological basis and the creative potential of language. He pointed out the infinite numbers of sentences we can produce with ease. He thereby defied behaviorist notions that we learn language by reinforcement. Even young children continually are producing novel sentences for which they could not have been reinforced in the past.

Add a Dash of Technology: Engineering, Computation, and Applied Cognitive Psychology

By the end of the 1950s, some psychologists were intrigued by the tantalizing notion that machines could be programmed to demonstrate the intelligent processing of information (Rychlak & Struckman, 2000). Turing (1950) suggested that soon it would be hard to distinguish the communication of machines from that of humans. He suggested a test, now called the "Turing test," that judges whether a computer program's output was indistinguishable from the output of humans (Cummins & Cummins, 2000). In other words, suppose you communicated with a computer and you could not tell that it was a computer. The computer then had passed the Turing test (Schonbein & Bechtel, 2003). (See Figure 1.4 ■.)



■ **Figure 1.4** **The Turing Test.** An interrogator communicates via computer screen and keyboard with a real human and a computer. The interrogator's task is to find out who is the computer by asking as many and varied questions as necessary.

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By 1956, a new phrase had entered our vocabulary. **Artificial intelligence (AI)** is defined as human attempts to construct systems that show intelligence and, particularly, the intelligent processing of information (*Merriam Webster's Collegiate Dictionary*, 2003). Chess-playing programs, which now can beat most humans, are examples of AI. Experts, however, greatly underestimated how difficult it would be to develop a computer that can think like a human being. Even in the twenty-first century, computers have trouble reading handwriting and understanding and responding to spoken language with the ease that humans do. For example, "Siri" is a program on mobile Apple devices like the iPhone. Apple calls her a "personal assistant" and you can ask Siri to place a call for you, put appointments on your calendar, or tell you the weather forecast for a particular place. Although the program is constantly being improved and can understand many questions or commands, it still is not able to understand you just like a human would—or anything close.

Many of the early cognitive psychologists became interested in cognitive psychology through applied problems. For example, according to Berry (2002), Donald Broadbent (1926–1993) claimed to have developed an interest in cognitive psychology through a puzzle regarding AT6 aircraft. The planes had two almost-identical levers under the seat. One lever was to pull up the wheels and the other to pull up the flaps. Pilots apparently regularly mistook one for the other, thereby crashing expensive planes upon takeoff. During World War II, many cognitive psychologists, including one of the senior author's advisors, Wendell Garner, consulted with the military in solving practical problems of aviation and other fields that arose out of warfare against enemy forces. Information theory, which sought to understand people's behavior in terms of how they process the kinds of bits of information processed by computers (Shannon & Weaver, 1963), also grew out of problems in engineering and informatics.

Advertising has extensively used applied cognitive psychology. John Watson, after he left Johns Hopkins University as a professor, became an extremely successful executive in an advertising firm and applied his knowledge of psychology to reach his success. Indeed, much of advertising applies principles from cognitive psychology to attract customers to products (Benjamin & Baker, 2004).

By the early 1960s, developments moved forward rapidly in what then was called "psychobiology" but now has been expanded and is called cognitive neuroscience, linguistics, anthropology, and AI. These developments, as well as the reactions against behaviorism by many mainstream psychologists, created an atmosphere ripe for revolution. Early cognitivists (e.g., Miller, Galanter, & Pribram, 1960; Newell, Shaw, & Simon, 1957) argued that traditional behaviorist accounts of behavior were inadequate precisely because they said nothing about how people think. One of the most famous early articles in cognitive psychology was, oddly enough, on "the magic number seven." George Miller (1956) noted that the number seven appeared in many different places in cognitive psychology, such as in the literature on perception and memory, and he wondered whether there was some hidden meaning in its frequent reappearance. For example, he found that most people can remember about seven items of information. In this work, Miller also introduced the concept of *channel capacity*, the upper limit with which an observer can match a response to information given to him or her. For example, if you can remember seven digits presented to you sequentially, your channel capacity for remembering digits is seven. Ulric Neisser's book *Cognitive Psychology* (Neisser, 1967) was especially critical in bringing cognitivism to prominence by informing undergraduates, graduate students, and academics about the newly developing field.

Neisser defined *cognitive psychology* as the study of how people learn, structure, store, and use knowledge. Subsequently, Allen Newell and Herbert Simon (1972) proposed detailed models of human thinking and problem solving from the most basic

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levels to the most complex. By the 1970s, cognitive psychology was recognized widely as a major field of psychological study with a distinctive set of research methods.

In the 1970s, Jerry Fodor (1973) popularized the concept of the modularity of mind. He argued that the mind has distinct modules, or special-purpose systems, to deal with linguistic and, possibly, other kinds of information. Modularity implies that the processes that are used in one domain of processing, such as the linguistic (Fodor, 1973) or the perceptual domain (Marr, 1982), operate independently of processes in other domains. An opposing view would be one of domain general processing, according to which the processes that apply in one domain, such as perception or language, apply in many other domains as well. Modular approaches are useful in studying some cognitive phenomena, such as language, but have proven less useful in studying other phenomena, such as intelligence, which seems to draw on many different areas of the brain in complex interrelationships.

Curiously, the idea of the mind as modular goes back at least to phrenologist Franz Joseph Gall (see Boring, 1950), who in the late-eighteenth century believed that the pattern of bumps and swells on the skull was directly associated with one's pattern of cognitive skills. Although phrenology itself was not a scientifically valid technique, the practice of mental cartography lingered and eventually gave rise to ideas of modularity based on modern scientific techniques.

CONCEPT CHECK

1. What is pragmatism, and how is it related to functionalism?
2. How are associationism and behaviorism both similar and different?
3. What is the fundamental idea behind Gestalt psychology?
4. What is the meaning of modularity of mind?
5. How does cognitivism incorporate elements of the schools that preceded it?

Research Methods in Cognitive Psychology

Researchers employ a variety of research methods. These methods include laboratory or other controlled experiments, neuroscientific research, self-reports, case studies, naturalistic observation, and computer simulations and AI. Each of these methods will be discussed in detail in this section. Which methods researchers use depends on their goals. Therefore, we will first look at research goals in cognitive psychology before we turn to the methods used to pursue these goals.

Goals of Research

Briefly, research goals include data gathering, data analysis, theory development, hypothesis formulation, hypothesis testing, and perhaps even application to settings outside the research environment. Often researchers simply seek to gather as much information as possible about a particular phenomenon. They may or may not have preconceived notions regarding what they may find while gathering the data. Their research focuses on describing particular cognitive phenomena, such as how people recognize faces or how they develop expertise.

Data gathering reflects an empirical aspect of the scientific enterprise. Once there are sufficient data on the cognitive phenomenon of interest, cognitive psychologists use various methods for drawing inferences from the data. Ideally, they use multiple converging types of evidence to support their hypotheses. Sometimes, just a quick glance at the data leads to intuitive inferences regarding patterns that emerge from those data. More commonly, however, researchers use various statistical means of analyzing the data.

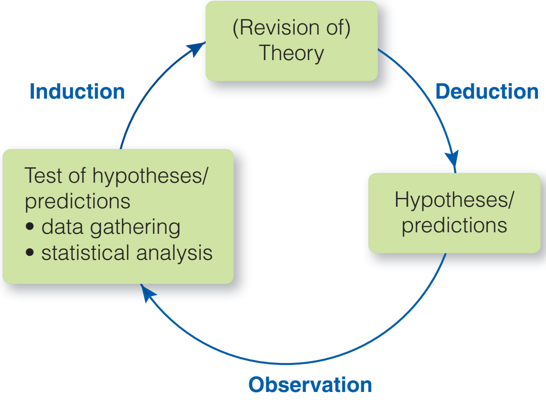
Data gathering and statistical analysis aid researchers in describing cognitive phenomena. No scientific pursuit could get far without such descriptions. However, most cognitive psychologists want to understand more than the *what* of cognition; most also seek to understand the *how* and the *why* of thinking. That is, researchers seek ways to explain cognition as well as to describe it. To move beyond descriptions, cognitive psychologists must leap from what is observed directly to what can be inferred regarding observations.

Suppose that we wish to study one particular aspect of cognition. An example would be how people comprehend information in textbooks. We usually start with a theory. A **theory** is an organized body of general explanatory principles regarding a phenomenon, usually based on observations. We test a theory to see whether it has the power to predict certain aspects of the phenomena with which it deals. In other words, our thought process is, "If our theory is correct, then whenever *x* occurs, outcome *y* should result." This process results in the generation of **hypotheses**, tentative proposals regarding expected empirical consequences of the theory, such as the outcomes of research.

Next, we test our hypotheses through experimentation. Even if particular findings appear to confirm a given hypothesis, the findings must be subjected to statistical analysis to determine their statistical significance. **Statistical significance** indicates the likelihood that a given set of results would be obtained if only chance factors were in operation. For example, a **statistical significance** level of 0.05 would mean that the likelihood of a given set of data would be a mere 5% if only chance factors were operating. Therefore, the results are not likely to be due merely to chance. Through this method, we can decide to retain or reject hypotheses.

Once our hypothetical predictions have been experimentally tested and statistically analyzed, the findings from those experiments may lead to further work. For example, the psychologist may engage in further data gathering, data analysis, theory development, hypothesis formulation, and hypothesis testing. On the basis of the hypotheses that were retained or rejected, the theory may have to be revised (see Figure 1.5 ■). In addition, many cognitive psychologists hope to use insights gained from research to help people use cognition in real-life situations. Some research in cognitive psychology

■ **Figure 1.5 Investigative Cycle.** Theories give rise to hypotheses that can be tested and often lead to a revision of the theory.



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is applied from the start. It seeks to help people improve their lives and the conditions under which they live their lives. Thus, basic research may lead to everyday applications. For each of these purposes, different research methods offer different advantages and disadvantages.

Distinctive Research Methods

Cognitive psychologists use various methods to explore how humans think. These methods include (1) laboratory or other controlled experiments, (2) neuroscientific research, (3) self-reports, (4) case studies, (5) naturalistic observation, and (6) computer simulations and AI. See Figure 1.6 ■ for descriptions and examples of each method. As the figure shows, each method offers distinctive advantages and disadvantages.

Experiments on Human Behavior

In controlled experimental designs, an experimenter usually will conduct research in a laboratory setting. The experimenter controls as many aspects of the experimental situation as possible. Basically, the two kinds of variables in any given experiment are independent and dependent variables. **Independent variables** are aspects of an investigation that are individually *manipulated*, or carefully regulated, by the experimenter, while other aspects of the investigation are held constant (i.e., not subject to variation). **Dependent variables** are outcome responses, the values of which depend on how one or more independent variables influence or affect the participants in the experiment. When you tell some student research participants that they will do very well on a task, but you do not say anything to other participants, the independent variable is the amount of information that the students are given about their expected task performance. The dependent variable is how well both groups actually perform the task—that is, their score on the math test.

When the experimenter manipulates the independent variables, he or she controls for the effects of irrelevant variables and observes the effects on the dependent variables (outcomes). These irrelevant variables that are held constant are called *control variables.* For example, when you conduct an experiment on people's ability to concentrate when subjected to different kinds of background music, you should make sure that the lighting in the room is always the same, and not sometimes extremely bright and other times dim. The variable of light needs to be held constant.

Another type of variable is the confounding variable. *Confounding variables* are a type of irrelevant variable that has been left uncontrolled in a study. For example, imagine you want to examine the effectiveness of two problem-solving techniques. You train and test one group under the first strategy at 6 A.M. and a second group under the second strategy at 6 P.M. In this experiment, time of day would be a confounding variable. In other words, time of day may be causing differences in performance that have nothing to do with the problem-solving strategy. Obviously, when conducting research, we must be careful to avoid the influence of confounding variables.

In implementing the experimental method, experimenters must use a representative and random sample of the population of interest. They must exert rigorous control over the experimental conditions so that they know that the observed effects can be attributed to variations in the independent variable and nothing else. For example, in the previously mentioned experiment, people's ability to concentrate did not depend on the general lighting conditions in the room, per se, because during a few sessions, the sun shone directly into the eyes of the subjects so that they had trouble seeing.

The experimenter also must randomly assign participants to the treatment and control conditions. For example, you would not want to end up in an experiment on concentration with lots of people with Attention Deficit Hyperactivity Disorder (ADHD) in

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METHOD	CONTROLLED LABORATORY EXPERIMENTS	NEUROSCIENTIFIC RESEARCH	SELF-REPORTS, SUCH AS VERBAL PROTOCOLS, SELF-RATINGS, DIARIES
Random assignment of subjects	Usually	Not usually	Not applicable
Experimental control of independent variables	Usually	Varies widely, depending on the particular technique	Probably not
Sample size	May be any size	Often small	Probably small
Sample representativeness	May be representative	Often not representative	May be representative
Ecological validity	Not unlikely; depends on the task and the context to which it is being applied	Unlikely under some circumstances	Maybe; see strengths and weaknesses
Information about individual differences	Usually de-emphasized	Yes	Yes
Strengths	• Easy to administer, score, and statistically analyze • High probability of drawing valid causal inferences	• Provides "hard" evidence of cognitive functions • Alternative view of cognitive processes • Possibility to develop treatments for cognitive deficits	• Access to introspective insights from participants' point of view
Weaknesses	• Difficulty in generalizing results beyond a specific place, time, and task setting • Discrepancies between behavior in real life and in the laboratory	• Limited access to appropriate subjects and expensive equipment (for most researchers) • Small samples • Decreased generalizability when abnormal brains or animal brains are investigated	• Inability to report on processes occurring outside conscious awareness • Verbal protocols and self-ratings: May influence cognitive process being reported • Discrepancies between actual cognition and recollected cognitive processes and products
Examples	Karpicke (2009) developed a laboratory task in which participants had to learn and recall Swahili-English word pairs. After subjects first recalled the meaning of a word, that pair was either dropped, presented twice more in a study period, or presented twice more in text periods. Subjects took a final recall test one week later.	New and colleagues (New et al., 2009) have found that borderline patients with Intermittent Explosive Disorder responded more aggressively to a provocation than did normal control subjects. The patients particularly show an increase in glucose consumption in brain areas associated with emotion like the amygdala and less activity in dorsal brain regions that serve to control aggression.	In a study about the relation between cortisol levels (which are stress-dependent) and sleep, self-rated health, and stress, participants kept diaries and collected saliva samples over four weeks (Dahlgren et al., 2009).

■ **Figure 1.6 Research Methods.** Cognitive psychologists use controlled experiments, neuroscientific research, self-reports, case studies, naturalistic observation, and computer simulations and artificial intelligence when studying cognitive phenomena.

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CASE STUDIES	NATURALISTIC OBSERVATIONS	COMPUTER SIMULATIONS AND ARTIFICIAL INTELLIGENCE
Highly unlikely	Not applicable	Not applicable
Highly unlikely	No	Full control of variables of interest
Almost certain to be small	Probably small	Not applicable
Not likely to be representative	May be representative	Not applicable
High ecological validity for individual cases; lower generalizability to others	Yes	Not applicable
Yes; richly detailed information regarding individuals	Possible, but emphasis is on environmental distinctions, not on individual differences	Not applicable
• Access to detailed information about individuals, including historical and current contexts • May lead to specialized applications for special groups (e.g., prodigies, persons with brain damage)	• Access to rich contextual information	• Exploration of possibilities for modeling cognitive processes • Allows clear hypothesis testing • Wide range of practical applications (e.g., robotics for performing dangerous tasks
• Applicability to other persons • Limited generalizability due to small sample size and nonrepresentativeness of sample	• Lack of experimental control • Possible influence on behavior due to presence of observer	• Limitations imposed by the hardware (i.e., the computer circuitry) and the software (i.e., the programs written by the researchers) • Simulations may imperfectly model the way that the human brain thinks
A case study with a breast cancer patient showed that a new technique (problem-solving therapy) can reduce anxiety and depression in cancer patients (Carvalho & Hopko, 2009).	A study using questionnaires and observation found that Mexicans on average consider themselves less sociable than U.S. Americans consider themselves; however, Mexicans behave much more sociably than U.S. Americans in their everyday lives (Ramirez-Esparza et al., 2009).	**Simulations:** Through detailed computations, David Marr (1982) attempted to simulate human visual perception and proposed a theory of visual perceptions based on his computer models. **AI:** Various AI programs have been written that can demonstrate expertise (e.g., playing chess), but they probably do so via different processes than those used by human experts.

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your experimental group, but no such people in your control group. If those requisites for the experimental method are fulfilled, the experimenter may be able to infer probable causality. That is, the researcher can infer how likely it is that the effect of the independent variable or variables (the treatment) on the dependent variable (the outcome) is not a result merely of chance, at least for the given population.

in the lab of **HENRY L. ROEDIGER, III**

The Science of the Mind

In 1620 Sir Francis Bacon wrote, "If you read a piece of text through twenty times, you will not learn it by heart so easily as if you read it ten times while attempting to recite from time to time and consulting the text when your memory fails." How did he know that? The answer is that he did not know, for sure, but based his judgment on his own personal experience. The case is interesting because Bacon was one of the originators of the scientific method and laid out the framework for experimental science.

Science in Bacon's time was applied to the natural world, what today would be called the physical sciences (chiefly, physics and chemistry). The idea that scientific methods could be applied to people was not even dreamt of and, had the notion been raised, it would have been hooted down. Human beings were not dross stuff; they had souls, they had free will—surely they could not be studied scientifically! It took another 250 years before pioneers would question this assumption and take the brave step to create a science of psychology, the study of the mind. The date usually given is 1879, when Wilhelm Wundt founded the first psychology laboratory in Leipzig, Germany.

Courtesy of the author

Henry L. Roediger, III

Edwin G. Boring, the great historian of psychology, wrote that the "application of the experimental method to the problem of mind is the great outstanding event in the study of the mind, an event to which no other is comparable" (1929, p. 659). Boring is right, and the textbook you hold relates the fascinating story of cognitive psychology, today's experimental study of mind.

But what about Bacon's assertion? Does reciting material really help one learn it more than studying it? This idea seems odd because in education we think of studying as being how we learn, and we think of testing as only measuring what has been learned.

My students and I have been studying the possible validity of Bacon's claim in a variety of experimental contexts (although, truth be told, we found the quotation after the studies were well under way). In our experiments, students learn materials (either simple sets of words or more complex text book passages—the material does not matter) by various combinations of studying and testing the material. The general finding is that retrieval (or reciting, as Bacon called it) during a test provides a great boost to later retention, much more so than repeated studying (Roediger & Karpicke, 2006; see Roediger & Butler, 2011 for a review).

Let us consider just one experiment here to make the point. Zaromb and Roediger (2010) gave students lists of words to remember in preparation for a test that would be given two days later. Students in one condition studied the material eight times with short breaks, but students in two other conditions received either two or four tests in place of some of the study trials. If *S* denotes a study trial and *T* denotes a test (or recitation), the three conditions can be labeled *SSSSSSSS*, *STSSSTSS*, or *STSTSTST*. If studying determines later recall, then the three conditions just listed should be ordered in terms of decreasing effectiveness (from eight to six to four study trials). If Bacon is right, however, the conditions should be ordered in increasing effectiveness for later retention (from zero to two to four test trials). The result: the proportion recalled two days later was 0.17, 0.25 and 0.39 for the three conditions in the order listed previously.

Sir Francis Bacon was right: Reciting is more effective than studying (although of course some studying is required). To my knowledge, no one has done the actual experiment he suggested (20 trials), but it would make a fine class project with 20 study trials for one condition or 10 study and 10 test trials for the other. By the way, self-testing on material is a good way to study for your courses. In our book, *Make It Stick: The Science of Successful Learning*, we suggest many other strategies for enhancing learning (Brown, Roediger, & McDaniel, 2014).

Many different dependent variables are used in cognitive-psychological research. Two common variables are percent correct (or its additive inverse, error rate) and reaction time. That is, the researcher investigates how many of the items the participant can answer correctly, or how long it takes him to respond to a stimulus under particular circumstances. These measures are popular because they can tell the investigator, respectively, the accuracy and speed of mental processing. Independent and dependent variables must be chosen with great care, because no matter what processes one is observing, what is learned from an experiment will depend almost exclusively on the variables one chooses to isolate from the often-complex behavior one is observing.

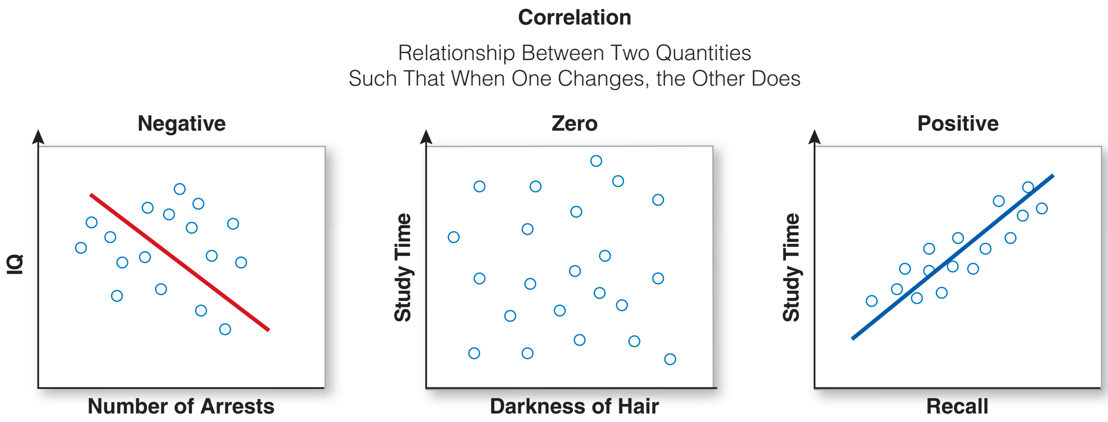
Psychologists who study cognitive processes with reaction time often use the *subtraction method*, which involves estimating the time a cognitive process takes by subtracting the amount of time information processing takes with the process from the time it takes without the process (Donders, 1868/1869). If you are asked to scan the five words *dog, cat, mouse, hamster, chipmunk* and to say whether the word *chipmunk* appears in it, and then are asked to scan the six words *dog, cat, mouse, hamster, chipmunk, lion* and to say whether *lion* appears, the difference in the reaction times might be taken, by some models of mental processing, roughly to indicate the amount of time it takes to process each stimulus.

Suppose the outcomes in the treatment condition show a statistically significant difference from the outcomes in the control condition. The experimenter then can infer the likelihood of a causal link between the independent variable(s) and the dependent variable. Because the researcher can establish a likely causal link between the given independent variables and the dependent variables, controlled laboratory experiments offer an excellent means of testing hypotheses.

Suppose that we wanted to see whether loud, distracting noises influence the ability to perform well on a particular cognitive task (e.g., reading a passage from a textbook and responding to comprehension questions). Ideally, we first would select a random sample of participants from within our total population of interest. We then would randomly assign each participant to a treatment condition or a control condition. Then we would introduce some distracting loud noises to the participants in our treatment condition. The participants in our control condition would not receive this treatment. We would present the cognitive task to participants in both the treatment condition and the control condition and then measure their performance by some means (e.g., speed and accuracy of responses to comprehension questions). Finally, we would analyze our results statistically. We thereby would examine whether the difference between the two groups reached statistical significance.

Suppose the participants in the treatment condition showed poorer performance at a statistically significant level than the participants in the control condition. We might infer that loud, distracting noises influenced the ability to perform well on this particular cognitive task.

In cognitive-psychological research, although the dependent variables may be diverse, they often involve various outcome measures of accuracy (e.g., frequency of errors), of response times, or of both. Among the myriad possibilities for independent variables are characteristics of the situation, of the task, or of the participants. For example, characteristics of the situation may involve the presence versus the absence of particular stimuli or hints during a problem-solving task. Characteristics of the task may involve reading versus listening to a series of words and then responding to comprehension questions. Characteristics of the participants may include age differences, differences in educational status, or differences based on test scores.



■ **Figure 1.7** **Correlation Charts.** Correlations range from –1 to 0 to 1.

On the one hand, characteristics of the situation or task may be manipulated through random assignment of participants to either the treatment or the control group. On the other hand, characteristics of the participant are not easily manipulated experimentally. For example, suppose the experimenter wants to study the effects of aging on speed and accuracy of problem solving. The researcher cannot randomly assign participants to various age-groups because people's ages cannot be manipulated (although participants of various age-groups can be assigned at random to various experimental conditions). In such situations, researchers often use other kinds of studies, for example, studies involving *correlation* (a statistical relationship between two or more attributes, such as characteristics of the participants or of a situation). Correlations are usually expressed through a correlation coefficient known as Pearson's *r*. Pearson's *r* is a number that can range from –1.00 (a negative correlation) to 0 (no correlation) to 1.00 (a positive correlation). See Figure 1.7 ■ for an illustration.

A correlation is a description of a relationship. The correlation coefficient describes the strength of the relationship. The closer the coefficient is to 1 (either positive or negative), the stronger the relationship between the variables is. The sign (positive or negative) of the coefficient describes the direction of the relationship. A positive relationship indicates that as one variable increases (e.g., vocabulary size), another variable also increases (e.g., reading comprehension). A negative relationship indicates that as the measure of one variable increases (e.g., fatigue), the measure of another decreases (e.g., alertness). No correlation—that is, when the coefficient is 0—indicates that there is no pattern or relationship in the change of two variables (e.g., intelligence and earlobe length). In this final case, both variables may change, but the variables do not vary together in a consistent pattern.

Correlational studies are often the method of choice when researchers do not want to deceive their subjects by using manipulations in an experiment or when they are interested in factors that cannot be manipulated ethically (e.g., lesions in specific parts of the human brain). However, because researchers do not have any control over the experimental conditions, causality cannot be inferred from correlational studies.

Findings of statistical relationships are highly informative. Their value should not be underrated. Also, because correlational studies do not require the random assignment of participants to treatment and control conditions, these methods may be applied flexibly. However, correlational studies generally do not permit unequivocal inferences regarding causality. As a result, many cognitive psychologists strongly prefer experimental data to correlational data.

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Neuroscientific Research

Through *neuroscientific research*, investigators study the relationship between cognitive performance and cerebral events and structures. Chapter 2 describes various specific techniques used in neuroscientific research. These techniques generally fall into three categories:

- techniques for studying an individual's brain *postmortem* (after the death of an individual), relating the individual's cognitive function before death to observable features of the brain
- techniques for studying images showing structures of or activities in the brain of an individual who is known to have a particular cognitive deficit
- techniques for obtaining information about cerebral processes during the normal performance of a cognitive activity

Postmortem studies offered some of the first insights into how specific *lesions* (areas of injury in the brain) may be associated with particular cognitive deficits. Such studies continue to provide useful insights into how the brain influences cognitive function. Recent technological developments also increasingly enable researchers to study individuals with known cognitive deficits *in vivo* (while the individual is alive). The study of individuals with abnormal cognitive functions linked to cerebral damage often enhances our understanding of normal cognitive functions.

Researchers also study normal cognitive functioning by studying cerebral activity in animal participants. Researchers often use animals for experiments involving neurosurgical procedures that cannot be performed on humans because such procedures would be difficult, unethical, or impractical. For example, studies mapping neural activity in the cortex have been conducted on cats and monkeys (e.g., neuroscientific research on how the brain responds to visual stimuli; see Chapter 3).

Can cognitive and cerebral functioning of animals and people with cognitive problems be generalized to apply to the cognitive and cerebral functioning of normal humans? Neuroscientists have responded to these questions in various ways. Technology permits researchers to study the dynamic cerebral activity of normal human participants during cognitive processing (see the brain-imaging techniques described in Chapter 2) for certain kinds of cognitive activity.

Self-Reports, Case Studies, and Naturalistic Observation

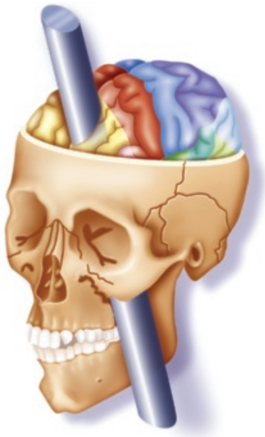
Individual experiments and neuropsychological studies often focus on precise specification of discrete aspects of cognition across individuals. To obtain richly textured information about how particular individuals think in a broad range of contexts, researchers may use other methods. These methods include the following:

- *self-reports* (an individual's own account of cognitive processes)
- *case studies* (in-depth studies of individuals)
- *naturalistic observation* (detailed studies of cognitive performance in everyday situations and nonlaboratory contexts)

Experimental research is most useful for testing hypotheses; however, research based on self-reports, case studies, and naturalistic observation is often particularly useful for the formulation of hypotheses. These methods are also useful to generate descriptions of rare events or processes that we have no other way to measure.

In specific circumstances, these methods may provide the only way to gather information. An example is the case of Genie, a girl who was locked in a room until the age of 13 years and thus provided with severely limited social and sensory experiences. As a result of her imprisonment, Genie had severe physical impairments and no language skills. Through case-study methods, information was collected about how she later began to learn language (Fromkin et al., 1974; Jones, 1995; LaPointe, 2005). It would have been unethical experimentally to deny a person any language experience for the first 13 years of life. Therefore, case-study methods are the only reasonable way to examine the results of someone being denied language and social exposure.

Traumatic brain injury is another condition that cannot be manipulated in humans in the laboratory. Therefore, when traumatic brain injury occurs, case studies are the only way to gather information. Consider the case of Phineas Gage, a railroad worker who, in 1848, had a large metal spike driven through his frontal lobes in a freak accident (Torregrossa, Quinn, & Taylor, 2008; see also Figure 1.8 ■). Mr. Gage surprisingly survived; however, his behavior and mental processes were drastically changed by the accident. We obviously cannot insert large metal rods into the brains of experimental participants. Therefore, in the case of traumatic brain injury, we must rely on case-study methods to gather information.


BSIP/Universal Images Group/Getty Images

■ **Figure 1.8 Phineas Gage.** When an explosion forced an iron rod through his head, Phineas Gage sustained frontal lobe damage. Gage was the subject of case studies both during his life and after his death.

The reliability of data based on self-reports depends on the candor of the participants. A participant may misreport information about his or her cognitive processes for a variety of reasons. These reasons can be intentional or unintentional. Intentional misreports can include trying to edit out unflattering information. Unintentional misreports may involve not understanding the question or not remembering the information accurately. For example, when a participant is asked about the problem-solving strategies he or she used in high school, the participant may not remember. The participant may try to be completely truthful in his or her reports. But reports involving recollected information (e.g., diaries, retrospective accounts, questionnaires, and surveys) are notably less reliable than reports provided during the cognitive processing under investigation. The reason is that participants sometimes forget what they did.

In studying complex cognitive processes, such as problem solving or decision making, researchers often use a verbal protocol. In a *verbal protocol*, the participants describe aloud all their thoughts and ideas during the performance of a given cognitive task (e.g., "I like the apartment with the swimming pool better, but I can't really afford it, so I might have to choose the one without the swimming pool.").

An alternative to a verbal protocol is for participants to report specific information regarding a particular aspect of their cognitive processing. For example, consider a study of insightful problem solving (see Chapter 11). Participants were asked at 15-second intervals to report numerical ratings indicating how close they felt they were to reaching a solution to a given problem. Unfortunately, even these methods of self-reporting have their limitations. What kind of limitations? Cognitive processes may be altered by the act of giving the report (e.g., processes involving brief forms of memory; see Chapter 5). Or cognitive processes may occur outside of conscious awareness (e.g., processes that do not require conscious attention or that take place so rapidly that we fail to notice them; see Chapter 4). To get an idea of some of the difficulties with self-reports, carry out the following *Investigating Cognitive Psychology: Self-Reports* tasks. Reflect on your experiences with self-reports.

Case studies (e.g., an in-depth study of individuals who are exceptionally gifted) and naturalistic observations (such as detailed observations of the performance of employees operating in nuclear power plants) may be used to complement findings from laboratory experiments. These two methods of cognitive research offer high **ecological validity**, the degree to which particular findings in one environmental context may be considered relevant outside of that context. As you probably know, *ecology* is the study of the interactive relationship between an organism (or organisms) and its environment. Many cognitive psychologists seek to understand the interactive relationship between human thought processes and the environments in which humans are thinking. Sometimes,

INVESTIGATING COGNITIVE PSYCHOLOGY

Self-Reports

1. Without looking at your shoes, try reporting aloud the various steps involved in tying your shoe.
2. Recall aloud what you did on your last birthday.
3. Now, actually tie your shoe (or something else, such as a string tied around a table leg), reporting aloud the steps you take. Do you notice any differences between task 1 and task 3?
4. Report aloud how you pulled into consciousness the steps involved in tying your shoe or your memories of your last birthday. Can you report exactly how you pulled the information into conscious awareness? Can you report which part of your brain was most active during each of these tasks?

cognitive processes that are commonly observed in one setting (e.g., in a laboratory) are not identical to those observed in another setting (e.g., in an air-traffic control tower or a classroom).

Computer Simulations and Artificial Intelligence

Digital computers played a fundamental role in the emergence of the study of cognitive psychology. One kind of influence is indirect—through models of human cognition based on models of how computers process information. Another kind is direct—through computer simulations and AI.

In *computer simulations*, researchers program computers to imitate a given human function or process. Examples are performance on particular cognitive tasks (e.g., manipulating objects within three-dimensional space) and performance of particular cognitive processes (e.g., pattern recognition). Some researchers have attempted to create computer models of the entire cognitive architecture of the human mind. Their models have stimulated heated discussions regarding how the human mind may function as a whole (see Chapter 8). Sometimes the distinction between simulation and AI is blurred. For example, certain programs are designed to simulate human performance and to maximize functioning simultaneously.

Consider a computer program that plays chess. There are two entirely different ways to conceptualize how to write such a program. One is known as brute force: A researcher constructs an algorithm that considers extremely large numbers of moves in a very short time, potentially beating human players simply by virtue of the number of moves it considers and the future potential consequences of these moves. The program would be viewed as successful to the extent that it beat the best humans. This kind of AI does not seek to represent how humans function, but done well, it can produce a program that plays chess at the highest possible level.

An alternative approach, simulation, looks at how chess grand masters solve chess problems and then seeks to function the way they do. The program would be successful if it chose, in a sequence of moves in a game, the same moves that the grand master would choose. It is also possible to combine the two approaches, producing a program that generally simulates human performance but can use brute force as necessary to win games.

Putting It All Together

Cognitive psychologists often broaden and deepen their understanding of cognition through research in cognitive science. **Cognitive science** is a cross-disciplinary field

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that uses ideas and methods from cognitive psychology, cognitive neuroscience, AI, philosophy, linguistics, and anthropology (Nickerson, 2005; Von Eckardt, 2005). Cognitive scientists use these ideas and methods to focus on the study of how humans acquire and use knowledge.

Cognitive psychologists also profit from collaborations with other kinds of psychologists. Examples include not only social psychologists (e.g., in the cross-disciplinary field of social cognition), psychologists who study motivation and emotion, and engineering psychologists (i.e., psychologists who study human-machine interactions), but also clinical psychologists who are interested in psychological disorders. There is also close exchange and collaboration with a number of other related fields. Psychiatrists are interested in how the brain works and how it influences our thinking, feeling, and reasoning. Anthropologists in turn may explore how reasoning and perception processes differ from one culture to the next. Computer specialists try to develop computer interfaces that are highly efficient, given the way humans perceive and process information. Traffic planners can use information from cognitive psychology to plan and construct traffic situations that result in a maximal overview for traffic participants and therefore, hopefully, fewer accidents.

CONCEPT CHECK

1. What is the meaning of "statistical significance"?
2. How do independent and dependent variables differ?
3. Why is the experimental method uniquely suited to drawing causal inferences?
4. What are some of the advantages and disadvantages of the case-study method?
5. How does a theory differ from a hypothesis?

Fundamental Ideas in Cognitive Psychology

Certain fundamental ideas keep emerging in cognitive psychology, regardless of the particular phenomenon. Here are what might be considered five fundamental ideas. These ideas crosscut some of the key themes listed at the end of this chapter.

1. *Empirical data and theories are both important—data in cognitive psychology can be fully understood only in the context of an explanatory theory, and theories are empty without empirical data.*

   Theories give meaning to data. Suppose that we know that people's ability to recognize information that they have seen is better than their ability to recall such information. As an example, they are better at recognizing whether they heard a word said on a list than they are at recalling the word without the word being given. This is an interesting empirical generalization, but it does not, in the absence of an underlying theory, provide *explanation.* Another important goal of science is also *prediction.* Theory can suggest under which circumstances limitations to the generalization should occur. Theory thus assists both in explanation and in prediction.

At the same time, theory without data is empty. Almost anyone can sit in an armchair and propose a theory—even a plausible sounding one. Science, however, requires empirical testing of such theories. Thus, theories and data depend on each other. Theories generate data collections, which help correct theories, which then lead to further data collections, and so forth.

2. *Cognition is generally adaptive, but not in all specific instances.*

   We can perceive, learn, remember, reason, and solve problems with great accuracy. And we do so even though we are constantly distracted by a plethora of stimuli. The same processes, however, that lead us to perceive, remember, and reason accurately in most situations also can lead us astray. Our memories and reasoning processes, for example, are susceptible to certain well-identified, systematic errors. For example, we tend to overvalue information that is easily available to us. Although this tendency generally helps us to make cognitive processes more efficient, we do this even when this information is not optimally relevant to the problem at hand.

3. *Cognitive processes interact with each other and with noncognitive processes.*

   Although cognitive psychologists try to study and often to isolate the functioning of specific cognitive processes, they know that these processes work together. For example, memory processes depend on perceptual processes. What you remember depends in part on what you perceive. But noncognitive processes also interact with cognitive ones. For example, you learn better when you are motivated to learn. Cognitive psychologists therefore seek to study cognitive processes not only in isolation but also in their interactions with each other and with noncognitive processes.

   One of the most exciting areas of cognitive psychology in the twenty-first century is at the interface between cognitive and biological levels of analysis. In recent years, it has become possible to localize activity in the brain associated with various kinds of cognitive processes. One has to be careful, however, about assuming that the biological activity is causal of the cognitive activity. Research shows that learning causes changes in the brain. In other words, cognitive processes can affect biological structures just as biological structures can affect cognitive processes. The cognitive system does not operate in isolation. It works in interaction with other systems.

4. *Cognition needs to be studied through a variety of scientific methods.*

   There is no one right way to study cognition. All cognitive processes need to be studied through a variety of methods. The more different kinds of techniques that lead to the same conclusion, the higher the confidence one can have in that conclusion. For example, suppose studies of reaction times, error rates, and patterns of individual differences all lead to the same conclusion. Then one can have much more confidence in the conclusion than if only one method led to that conclusion.

   All these methods, however, must be *scientific.* They enable us to disconfirm our expectations when those expectations are wrong. Nonscientific methods do not have this feature. For example, methods of inquiry that simply rely on faith or authority to determine truth may have value in our lives, but they are not scientific.

5. *All basic research in cognitive psychology may lead to applications, and all applied research may lead to basic understandings.*

   But the truth is that the distinction between basic and applied research often is not clear at all. Research that seems like it will be basic often leads to immediate applications. Similarly, research that seems like it will be applied sometimes leads quickly to basic understandings. For example, a basic finding

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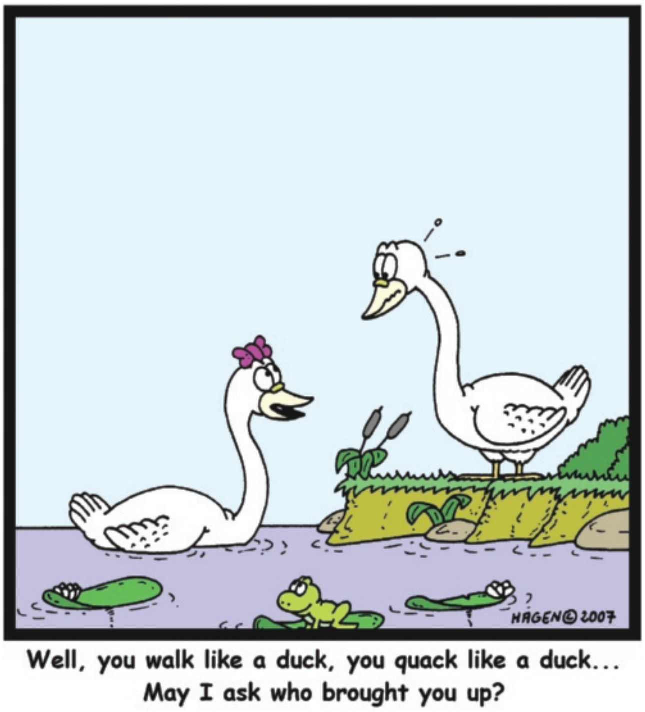
from research on memory is that learning is superior when it is spaced out over time rather than crammed into a short time interval. This basic finding has an immediate application to study strategies. At the same time, research on eyewitness testimony, which seems on its face to be very applied, has enhanced our basic understanding of memory systems and of the extent to which humans construct their own memories.

In this book, we emphasize the underlying common ideas and organizing themes across cognitive psychology, rather than simply stating the facts. We follow this path to help you perceive large, meaningful patterns within the domain of cognitive psychology. We also try to give you some idea of how cognitive psychologists think and how they structure their field in their day-to-day work. We hope that this approach will help you to contemplate problems in cognitive psychology at a deeper level than might otherwise be possible. Ultimately, the goal of cognitive psychologists is to understand not only how people may think in their laboratories but also how they think in their everyday lives.


HAGEN © 2007
Well, you walk like a duck, you quack like a duck...
May I ask who brought you up?

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Nature vs. nurture: Both our genes and our environment may influence what we are, how we behave, and how we think.

Key Themes in Cognitive Psychology

If we review the important ideas in this chapter, we discover some of the major themes that underlie cognitive psychology, such as nature versus nurture and rationalism versus empiricism. These, and the other key themes listed here, address the core of the nature of the human mind. These themes appear again and again in the study of cognitive psychology.

As you read each of the following chapters, think of the topics in terms of how they relate to the major themes in cognitive psychology. You will be encountering these themes throughout this text and can review them in each chapter's "Key Themes" section.

Note that these questions can be posed in the "either/or" form of thesis/antithesis or in the "both/and" form of a synthesis of views or methods. The synthesis view often proves more useful than one extreme position or another. For example, our nature may provide an inherited framework for our distinctive characteristics and patterns of thinking and acting. But our nurture may shape the specific ways in which we flesh out that framework.

We may use empirical methods for gathering data and for testing hypotheses. But we may use rationalist methods for interpreting data, constructing theories, and formulating hypotheses based on theories. Our understanding of cognition deepens when we consider both basic research in fundamental cognitive processes and applied research regarding effective uses of cognition in real-world settings. Syntheses are constantly evolving. What today may be viewed as a synthesis tomorrow may be viewed as an extreme position or vice versa.

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Remember, each of the topics in this text (perception, memory, and so on) can be examined using these seven major themes in cognitive psychology:

1. *Nature versus nurture*
   We can explore how covariations and interactions in the environment (e.g., an impoverished environment) adversely affect someone whose genes otherwise might have led to success in a variety of tasks.
2. *Rationalism versus empiricism*
   We can combine theory with empirical methods to learn the most we can about cognitive phenomena.
3. *Structures versus processes*
   Instead of focusing solely on the study of the contents or of the processes of the mind, we can explore how mental processes operate on mental structures.
4. *Domain generality versus domain specificity*
   When studying processes, we can explore which might be domain general and which might be domain specific.
5. *Validity of causal inferences versus ecological validity*
   We can combine a variety of methods, including laboratory methods and more naturalistic ones, to converge on findings that hold up, regardless of the method of study.
6. *Applied versus basic research*
   We can combine the two kinds of research so that basic research leads to applied research, which leads to further basic research, and so on.
7. *Biological versus behavioral methods*
   We can try to synthesize biological and behavioral methods so that we understand cognitive phenomena at multiple levels of analysis.

SUMMARY

1. **What is cognitive psychology?** Cognitive psychology is the study of how people perceive, learn, remember, and think about information.
2. **How did psychology develop as a science?** Beginning with Plato and Aristotle, people have contemplated how to gain understanding of the truth. Plato held that rationalism offers the clear path to truth, whereas Aristotle espoused empiricism as the route to knowledge. Centuries later, Descartes extended Plato's rationalism, whereas Locke elaborated on Aristotle's empiricism. Kant offered a synthesis of these apparent opposites. Decades after Kant proposed his synthesis, Hegel observed how the history of ideas seems to progress through a *dialectical* process.
3. **How did cognitive psychology develop from psychology?** By the twentieth century, psychology had emerged as a distinct field of study. Wundt focused on the structures of the mind (leading to *structuralism*), whereas James and Dewey focused on the processes of the mind *(functionalism).*

   Emerging from this dialectic was *associationism*, espoused by Ebbinghaus and Thorndike. It paved the way for behaviorism by underscoring the importance of mental associations. Another step toward behaviorism was Pavlov's discovery of the principles of classical conditioning. Watson and, later, Skinner were the chief proponents of *behaviorism.* It focused entirely on observable links between an organism's behavior and particular environmental

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contingencies that strengthen or weaken the likelihood that particular behaviors will be repeated. Most behaviorists dismissed entirely the notion that there is merit in psychologists trying to understand what is going on in the mind of the individual engaging in the behavior.

Tolman and subsequent behaviorist researchers noted the role of cognitive processes in influencing behavior. A convergence of developments across many fields led to the emergence of *cognitive psychology* as a discrete discipline, spearheaded by such notables as Neisser.

4. **How have other disciplines contributed to the development of theory and research in cognitive psychology?** Cognitive psychology has roots in philosophy and physiology, which merged to form the mainstream of psychology. As a discrete field of psychological study, cognitive psychology also profited from cross-disciplinary investigations.

   Fields relevant to cognitive psychology include linguistics (e.g., How do language and thought interact?), biological psychology (e.g., What are the physiological bases for cognition?), anthropology (e.g., What is the importance of the cultural context for cognition?), and technological advances like artificial intelligence (e.g., How do computers process information?).
5. **What methods do cognitive psychologists use to study how people think?** Cognitive psychologists use a broad range of methods, including experiments, neuroscientific techniques, self-reports, case studies, naturalistic observation, and computer simulations and artificial intelligence.
6. **What are the current issues and various fields of study within cognitive psychology?** Some of the major issues in the field focus on how to pursue knowledge. Psychological work can be done
   - by using both *rationalism* (which is the basis for theory development) and *empiricism* (which is the basis for gathering data);
   - by *underscoring* the importance of cognitive structures and of cognitive processes;
   - by *emphasizing* the study of domain-general and of domain-*specific* processing;
   - by striving for a high degree of experimental control (which better permits causal inferences) and for a high degree of *ecological validity* (which better allows generalization of findings to settings outside of the laboratory); and
   - by conducting basic research seeking fundamental insights about cognition and applied research seeking effective uses of cognition in real-world settings.

   Although positions on these issues may appear to be diametrical opposites, often apparently antithetical views may be synthesized into a form that offers the best of each of the opposing viewpoints.

   Cognitive psychologists study biological bases of cognition as well as attention, consciousness, perception, memory, mental imagery, language, problem solving, creativity, decision making, reasoning, developmental changes in cognition across the life span, human intelligence, artificial intelligence, and various other aspects of human thinking.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

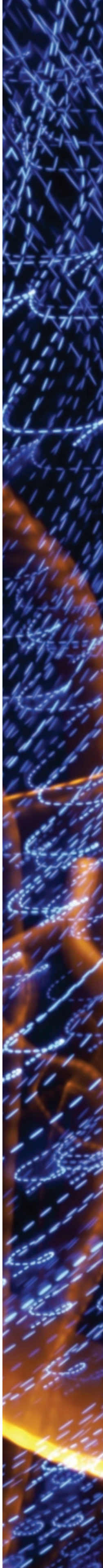
1. Describe the major historical schools of psychological thought leading up to the development of cognitive psychology.
2. Describe some of the ways in which philosophy, linguistics, and artificial intelligence have contributed to the development of cognitive psychology.
3. Compare and contrast the influences of Plato and Aristotle on psychology.
4. Analyze how various research methods in cognitive psychology reflect empiricist and rationalist approaches to gaining knowledge.
5. Design a rough sketch of a cognitive psychological investigation involving one of the research methods described in this chapter. Highlight both the advantages and the disadvantages of using this particular method for your investigation.
6. This chapter describes cognitive psychology as the field is at present. How might you speculate that the field will change in the next 50 years?
7. How might an insight gained from basic research lead to practical uses in an everyday setting?
8. How might an insight gained from applied research lead to a deepened understanding of the fundamental features of cognition?

KEY TERMS

artificial intelligence (AI), p. 16
associationism, p. 10
behaviorism, p. 11
cognitive psychology, p. 3
cognitive science, p. 27
cognitivism, p. 14
dependent variables, p. 19
dialectic, p. 4
ecological validity, p. 26
empiricist, p. 6
functionalism, p. 9
gestalt psychology, p. 14
heuristics, p. 4
hypotheses, p. 18
independent variables, p. 19
intelligence, p. 5
introspection, p. 7
pragmatists, p. 10
rationalist, p. 6
statistical significance, p. 18
structuralism, p. 7
theory, p. 18

Cognitive Neuroscience

2



CHAPTER OUTLINE

Cognition in the Brain: The Anatomy and Mechanisms of the Brain
  Gross Anatomy of the Brain: Forebrain, Midbrain, and Hindbrain
    The Forebrain
    The Midbrain
    The Hindbrain
  Cerebral Cortex and Localization of Function
    Hemispheric Specialization
    Lobes of the Cerebral Hemispheres
  Neuronal Structure and Function
Viewing the Structures and Functions of the Brain
  Postmortem Studies
  Studying Live Nonhuman Animals
  Studying Live Humans
    Electrical Recordings
    Static Imaging Techniques
    Metabolic Imaging
Brain Disorders
  Stroke
  Brain Tumors
  Head Injuries
Key Themes
Summary
Thinking about Thinking: Analytical, Creative, and Practical Questions
Key Terms
Media Resources

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**

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Here are some of the questions we will explore in this chapter:

1. What are the fundamental structures and processes within the brain?
2. How do researchers study the major structures and processes of the brain?
3. What have researchers found as a result of studying the brain?

BELIEVE IT OR NOT

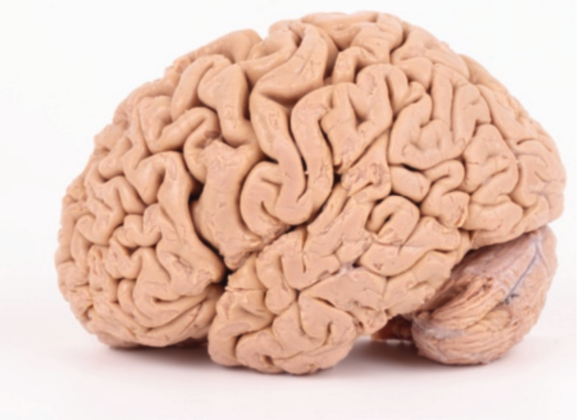
Does Your Brain Use Less Power Than Your Desk Lamp?

The brain is one of the premier users of energy in the human body. As much as 20% of the energy in your body is consumed by your brain, although it accounts for only about 2% of your body mass. This may come as no surprise, given that you need your brain for almost anything you do, from moving your legs to walk to reading this book, to talking to your friend on the phone. Even seeing what is right in front of your eyes takes a huge amount of processing by the brain, as you will see in Chapter 3. And yet, for all the amazing things your brain achieves, it does not use much more energy than your computer and monitor when they are "asleep." It is estimated that your brain uses about 12 to 20 watts of power. Your sleeping computer consumes about 10 watts when it's on, and 150 watts together with its monitor or even more when it's working. Even the lamp on your desk uses more power than your brain. Your brain performs many more tasks than your desk lamp or computer. Just think about all you'd have to eat if your brain consumed as much energy as those devices (Drubach, 1999). You'll learn more about how your brain works in this chapter.

Our brains are a central processing unit for everything we do. But how do our brains relate to our bodies? Are they connected or separate? Do our brains define who we are? An ancient legend from India (Rosenzweig & Leiman, 1989) tells of Sita. She marries one man but is attracted to another. These two frustrated men behead themselves. Sita, bereft of them both, desperately prays to the goddess Kali to bring the men back to life. Sita is granted her wish. She is allowed to reattach the heads to the bodies. In her rush to bring the two men back to life, Sita mistakenly switches their heads. She attaches them to the wrong bodies. Now, to whom is she married? Who is who?

The mind–body issue has long interested philosophers and scientists. Where is the mind located in the body, if at all? How do the mind and body interact? How are we able to think, speak, plan, reason, learn, and remember? What are the physical bases for our cognitive abilities? These questions all probe the relationship between cognitive psychology and neurobiology. Some cognitive psychologists seek to answer such questions by studying the biological bases of cognition. Cognitive psychologists are especially concerned with how the anatomy (physical structures of the body) and the physiology (functions and processes of the body) of the nervous system affect and are affected by human cognition.

Cognitive neuroscience studies how the brain and other aspects of the nervous system are linked to cognitive processing and, ultimately, to behavior. The **brain** is the organ in our bodies that most directly controls our thoughts, emotions, and motivations



Joe Petersburger / Getty images

Figure 2.1 The Brain. What does a brain actually look like? Here you can see a side view of a human brain. Subsequent figures detail some of the main features of the brain.

(Gloor, 1997; Rockland, 2000; Shepherd, 1998). Figure 2.1 ■ shows photos of what the brain actually looks like. We usually think of the brain as being at the top of the body's hierarchy—as the boss, with various other organs responding to it. Like any good boss, however, it listens to and is influenced by its subordinates, the other organs of the body. Thus, the brain is reactive as well as directive.

A major focus of brain research is localization of function. **Localization of function** refers to the specific areas of the brain that control specific skills or behaviors. Facts about particular brain areas and their function are interspersed throughout this chapter and also throughout the whole book.

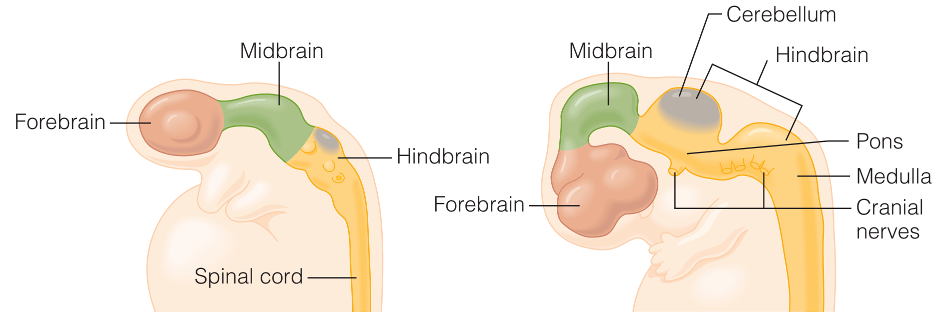
Our exploration of the brain starts with the anatomy of the brain. We will look at the gross anatomy of the brain as well as at neurons and the ways in which information is transmitted in the brain. Then we will explore the methods scientists use to examine the brain, its structures, and its functions. And finally, we will learn about brain disorders and how they inform cognitive psychology.

Cognition in the Brain: The Anatomy and Mechanisms of the Brain

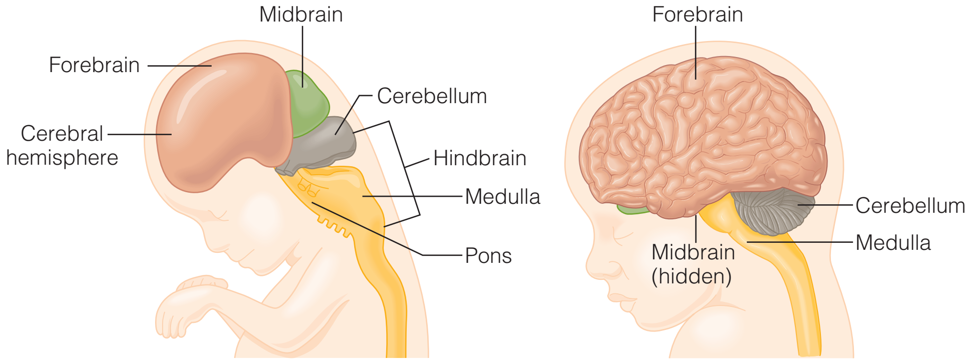
The **nervous system** is the basis for our ability to perceive, adapt to, and interact with the world around us (Gazzaniga, 1995b, 2000; Gazzaniga, Ivry, & Mangun, 2014). The brain is the supreme organ of the nervous system. The part of the brain that controls many of our thought processes is the cerebral cortex. Let's have a look at the structure of the brain.

Gross Anatomy of the Brain: Forebrain, Midbrain, and Hindbrain

What have scientists discovered about the human brain? The brain has three major regions: forebrain, midbrain, and hindbrain. These labels do not correspond exactly to locations of regions in an adult or even a child's head. Rather, the terms come from the front-to-back physical arrangement of these parts in the nervous system of a developing



(a) 3 weeks **(b)** 7 weeks



(c) 11 weeks **(d)** At birth

■ **Figure 2.2 Fetal Brain Development.** Over the course of embryonic and fetal development, the brain becomes more highly specialized and the locations and relative positions of the hindbrain, the midbrain, and the forebrain change from conception to term.

Source: Adapted from *In Search of the Human Mind* by Robert J. Sternberg, 1995 by Harcourt Brace & Company.

embryo. Initially, the *forebrain* is generally the farthest forward, toward what becomes the face. The *midbrain* is next in line. And the *hindbrain* is generally farthest from the forebrain, near the back of the neck [Figure 2.2(a) ■]. As the fetus develops, the relative orientations change so that the forebrain is almost a cap on top of the midbrain and hindbrain. Figures 2.2(b) ■, 2.2(c) ■, and 2.2(d) ■ show the changing locations and relationships of the forebrain, the midbrain, and the hindbrain over the course of development of the brain. You can see how they develop, from an embryo a few weeks after conception to birth.

The Forebrain

The forebrain is the region of the brain located toward the top and front of the brain. It includes the cerebral cortex, the basal ganglia, the limbic system, the thalamus, and the hypothalamus (Figure 2.3 ■). The cerebral cortex is the outer layer of the cerebral hemispheres. It plays a vital role in our thinking and other mental processes. It therefore merits a special section in this chapter, which follows the present discussion of the major structures and functions of the brain. The *basal ganglia* (singular: ganglion) are collections of neurons crucial to motor function. Dysfunction of the basal ganglia can result in motor deficits. These deficits include tremors, involuntary movements, changes in posture and muscle tone, and slowness of movement. Deficits are observed in Parkinson's disease and Huntington's disease. Both of these diseases entail severe motor symptoms (Gutierrez-Garralda et al., 2013; Lerner & Riley, 2008; Lewis & Barker, 2009; Rockland, 2000).

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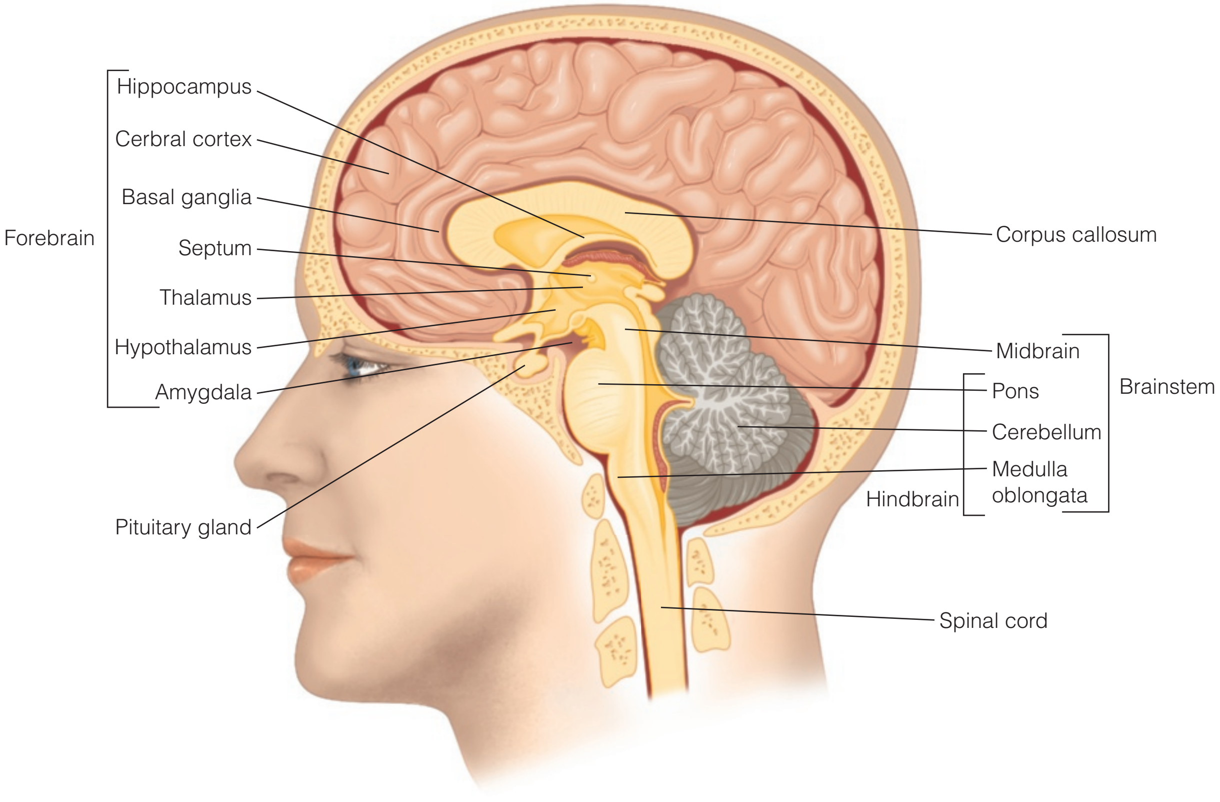

■ **Figure 2.3 Structures of the Brain.** The forebrain, the midbrain, and the hindbrain contain structures that perform essential functions for survival and for high-level thinking and feeling.

Source: Adapted from *Psychology: In Search of the Human Mind* by Robert J. Sternberg, 2000 by Harcourt Brace & Company.

The **limbic system** is important to emotion, motivation, memory, and learning. Animals such as fish and reptiles, which have relatively undeveloped limbic systems, respond to the environment almost exclusively by instinct. Mammals and especially humans have more developed limbic systems. Our limbic system allows us to suppress instinctive responses (e.g., the impulse to strike someone who accidentally causes us pain). Our limbic systems help us adapt our behaviors flexibly in response to our changing environment. The limbic system comprises three central interconnected cerebral structures: the septum, the amygdala, and the hippocampus.

The **septum** is involved in anger and fear (Breedlove & Watson, 2013). The **amygdala** plays an important role in emotion as well, especially in anger and aggression (Adolphs, 2003; Derntl et al., 2009). Stimulation of the amygdala commonly results in fear. It can be evidenced in various ways, such as through palpitations, fearful hallucinations, or frightening flashbacks in memory (Engin & Treit, 2008; Gloor, 1997; Rockland, 2000).

Damage to (lesions in) or removal of the amygdala can result in maladaptive lack of fear. In the case of lesions to the animal brain, the animal approaches potentially dangerous objects without hesitation or fear, or can no longer adequately learn fear reactions when it encounters dangerous situations (Adolphs et al., 1994; Frackowiak et al., 1997; Kazama et al., 2012). The amygdala also enhances the perception of emotional stimuli. If someone has a lesion in his or her amygdala, the perception of emotional stimuli is impaired (Anderson & Phelps, 2001; Tottenham, Hare, & Casey, 2009). For

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example, when people are presented with a number of words and then have to remember them, they usually remember negative words (such as *murder*) better than neutral words. In people with lesions to the amygdala, this is not the case. Additionally, people with autism display limited activation in the amygdala. A well-known theory of autism suggests that the disorder involves dysfunction of the amygdala, which leads to the social impairment that is typical of persons with autism, for example, difficulties in evaluating people's trustworthiness or recognizing emotions in faces (Adolphs, Sears, & Piven, 2001; Baron-Cohen et al., 2000; Howard et al., 2000; Kleinhans et al., 2009). Two other effects of lesions to the amygdala can be visual agnosia (inability to recognize objects) and hypersexuality (Steffanaci, 1999).

The **hippocampus** is essential in memory formation (Eichenbaum, 1999, 2002, 2011; Gluck, 1996; Manns & Eichenbaum, 2006; O'Keefe, 2003). It gets its name from the Greek word for "seahorse," its approximate shape. The hippocampus is essential for flexible learning, seeing relationships among items learned and spatial memory (Eichenbaum, 1997; Forcelli et al., 2014; Kaku, 2014; Squire, 1992). The hippocampus also appears to keep track of where things are and how these things are spatially related to each other. In other words, it monitors what is where (Cain, Boon, & Corcoran, 2006; Howland et al., 2008; McClelland et al., 1995; Tulving & Schacter, 1994). We return to the role of the hippocampus in Chapter 5.

People who have suffered damage to or removal of the hippocampus still can recall existing memories—for example, they can recognize old friends and places—but they are unable to form new memories (relative to the time of the brain damage). New information—new situations, people, and places—remains forever new. A disease that produces loss of memory function is **Korsakoff's syndrome**. Other symptoms include apathy, paralysis of muscles controlling the eye, and tremor. This loss is believed to be associated with deterioration of the hippocampus and is caused by a lack of thiamine (vitamin B-1) in the brain. The syndrome can result from excessive alcohol use, dietary deficiencies, or eating disorders.

There is a renowned case of a now-deceased patient known as H. M. (but whose real name was Henry Molaison), who after brain surgery retained his memory for events that transpired before the surgery but had no memory for events after the surgery. This case is another illustration of memory problems forming because of hippocampus damage (see Chapter 5 for more on H. M.). Disruption in the hippocampus appears to result in deficits in declarative memory (i.e., memory for pieces of information), but it does not result in deficits in procedural memory (i.e., memory for courses of action; Rockland, 2000).

The **thalamus** relays incoming sensory information through groups of neurons that project to the appropriate region in the cortex. Most of the sensory input into the brain passes through the thalamus, which is approximately in the center of the brain, at about eye level. To accommodate all of the types of information that must be sorted out, the thalamus is divided into a number of nuclei (groups of neurons of similar function). Each nucleus receives information from specific senses. The information is then relayed to corresponding specific areas in the cerebral cortex. The thalamus also helps in the control of sleep and waking. When the thalamus malfunctions, the result can be pain, tremor, amnesia, impairment of language, and disruptions in waking and sleeping (Cipolotti et al., 2008; Rockland, 2000; Steriade, Jones, & McCormick, 1997). In cases of schizophrenia, imaging and in vivo studies reveal abnormal changes in the thalamus (Clinton & Meador-Woodruff, 2004). These abnormalities result in difficulties in filtering stimuli and focusing attention, which in turn can explain why people suffering from schizophrenia experience symptoms such as hallucinations and delusions.

The **hypothalamus** regulates behavior related to species survival: fighting, feeding, fleeing, and mating. The hypothalamus also helps regulate emotions and react to stress

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(Malsbury, 2003). It interacts with the limbic system. The small size of the hypothalamus (from Greek *hypo-*, "under"; located at the base of the forebrain, beneath the thalamus) belies its importance in controlling many bodily functions (Table 2.1 ■). The hypothalamus plays a role in sleep: Dysfunction and neural loss within the hypothalamus are

Table 2.1 Major Structures and Functions of the Brain

Region of the Brain	Major Structures within the Regions	Functions of the Structures
Forebrain	Cerebral cortex (outer layer of the cerebral hemispheres)	Involved in • receiving and processing sensory information, • thinking and other cognitive processing, and • planning and sending motor information
	Basal ganglia (collections of nuclei and neural fibers)	Crucial to the function of the motor system
	Limbic systems (hippocampus, amygdala, and septum)	Involved in learning, emotions, and motivation
	Thalamus	Transmits sensory information coming to the cerebral cortex; includes several nuclei (groups of neurons) specializing in perception of visual stimuli, auditory stimuli, pressure and pain, and information that helps us sense physical balance and equilibrium
	Hypothalamus	Involved in • the endocrine system; • autonomic nervous system; • survival behavior (e.g., fighting, feeding, fleeing, and mating); • consciousness; and • emotions, pleasure, pain, and stress reactions
Midbrain	Superior colliculi (on top)	Involved in vision (especially visual reflexes)
	Inferior colliculi (below)	Involved in hearing
	Reticular activating system (also extends into the hindbrain)	Important in controlling • consciousness (sleep arousal), • attention, • cardiorespiratory function, and • movement
	Gray matter, red nucleus, substantia nigra, and ventral region	Important in controlling movement
Hindbrain	Cerebellum	Essential to balance, coordination, and muscle tone
	Pons (also contains part of the reticular activating system)	Involved in • consciousness, • facial nerves, and • bridging neural transmissions from one part of the brain to another
	Medulla oblongata	Nerves cross here from one side of the body to opposite side of the brain; involved in cardiorespiratory function, digestion, and swallowing

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noted in cases of narcolepsy, whereby a person falls asleep often and at unpredictable times (Lodi et al., 2004; Mignot, Taheri, & Nishino, 2002). The hypothalamus also is important for the functioning of the endocrine system. It is involved in stimulating the pituitary glands, through which a range of hormones are produced and released (Gazzaniga, Ivry, & Mangun, 2013).

Structures in the forebrain, midbrain, and hindbrain perform functions essential for survival as well as for high-level thinking and feeling. For a summary of the major structures and functions of the brain, as discussed in this section, see Table 2.1.

The Midbrain

The midbrain helps to control eye movement and coordination. Table 2.1 lists several structures and corresponding functions of the midbrain. By far the most indispensable of these structures is the **reticular activating system (RAS)**. Also called the "reticular formation," the RAS is a network of neurons essential to regulating consciousness, including sleep; wakefulness; arousal; attention to some extent; and vital functions, such as heartbeat and breathing (Sarter, Bruno, & Berntson, 2003).

The RAS also extends into the hindbrain. Both the RAS and the thalamus are essential to our conscious awareness of or control over our existence. The hindbrain, along with the thalamus, midbrain, and hypothalamus, make up the **brainstem**, which connects the forebrain to the spinal cord.

Physicians make a determination of brain death based on the function of the brainstem. Specifically, a physician must determine that the brainstem has been damaged so severely that various reflexes of the head (e.g., the pupillary reflex) are absent for more than 12 hours, or the brain must show no electrical activity or cerebral circulation of blood (Berkow, 1992; Shappell et al., 2013).

The Hindbrain

The hindbrain comprises the medulla oblongata, the pons, and the cerebellum.

The **medulla oblongata** controls heart activity and largely controls breathing, swallowing, and digestion. The medulla is also the place at which nerves from the right side of the body cross over to the left side of the brain and nerves from the left side of the body cross over to the right side of the brain. The medulla oblongata is an elongated interior structure located at the point at which the spinal cord enters the skull and joins with the brain. The medulla oblongata, which contains part of the RAS, helps to keep us alive.

The **pons** contains neural fibers that pass signals from one part of the brain to another. Its name derives from the Latin for "bridge," as it serves a bridging function. The pons also contains a portion of the RAS and nerves serving parts of the head and face. The **cerebellum** (from Latin, "little brain") controls bodily coordination, balance, and muscle tone, as well as some aspects of memory involving procedure-related movements (see Chapters 7 and 8) (Middleton & Helms Tillery, 2003). The prenatal development of the human brain roughly corresponds to the evolutionary development of the human brain within the species as a whole. Specifically, the hindbrain is evolutionarily the oldest and most primitive part of the brain. It also is the first part of the brain to develop prenatally. The midbrain is a relatively newer addition to the brain in evolutionary terms. It is the next part of the brain to develop prenatally. Finally, the forebrain is the most recent evolutionary addition to the brain. It is the last of the three portions of the brain to develop prenatally.

For cognitive psychologists, the most important of these evolutionary trends is the increasing neural complexity of the brain. The evolution of the human brain has offered

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us the enhanced ability to exercise voluntary control over behavior. It has also strengthened our ability to plan and to contemplate alternative courses of action. These ideas are discussed in the next section with respect to the cerebral cortex.

in the lab of **MARTHA FARAH**

Cognitive Neuroscience and Childhood Poverty

Around the time I had my daughter, I shifted my research focus to developmental cognitive neuroscience. People naturally assumed that these two life changes were related, and they were—but not in the way people thought. What captured my interest in brain development was not principally watching my daughter grow, as wondrous a process as that was. Rather, it was getting to know the babysitters who entered our lives, and learning about theirs.

Martha Farah

Courtesy of the author

These babysitters were young women of low socioeconomic status (SES), who grew up in families dependent on welfare and supported their own young children with a combination of state assistance supplemented with cash wages from babysitting. As caregivers for my child, they were not merely hired help; they were people I liked, trusted, and grew to care about. And as we became closer, and I spent more time with their families, I learned about a world very different from my own.

The children of these inner city families started life with the same evident potential as my own child, learning words, playing games, asking questions, and grappling with the challenges of cooperation, discipline, and self-control. But they soon found their way onto the same dispiriting life trajectories as their parents, with limited skills, options, hope. As a mother, I found it heartbreaking. As a scientist, I wanted to understand.

This led to a series of studies in which my collaborators and I tried first to simply document the effects of childhood poverty in terms of cognitive neuroscience's description of the mind, and then to explain the effects of poverty in terms of more specific, mechanistic causes. With Kim Noble, then a graduate student in my lab, we assessed the functioning of five different neurocognitive systems in kindergarteners of low and middle SES. We found the most pronounced effects in language and executive function systems. These results were replicated and expanded upon in additional studies with Noble and with Hallam Hurt, a pediatrician collaborator. In first graders and in middle school students, we again found striking SES disparities in language and executive function, as well as in declarative memory. Assuming that these disparities are the result of different early life experiences, what is it about growing up poor that would interfere with the development of these specific systems?

In one study, we made use of data collected earlier on the middle school children just mentioned. We found that their language ability in middle school was predicted by the amount of cognitive stimulation they experienced as 4-year-olds—being read to, being taken on trips, and so on. In contrast, we found that their declarative memory ability in middle school was predicted by the quality of parental nurturance that they received as young children—being held close, being paid attention to, and so on. The latter finding might seem an odd association. Why would affectionate parenting have anything to do with memory? Yet research with animals shows that when a young animal is stressed the resulting stress hormones can damage the hippocampus, a brain area important for both stress regulation and memory. This research has also shown that more nurturing maternal behavior can buffer the young animal's hippocampus against the effects of stress. This is consistent with the hypothesis that the stressful environment of poverty affects hippocampal development, with additional help or hindrance from parenting.

My daughter is now 19, and the field of poverty neuroscience is growing up too! Many research groups are now studying SES and child development through the lens of neuroscience. Brain imaging by our group and others shows structural and functional differences in the brain. One recent study of hippocampal volume in children found SES differences and also found that these differences were attributable to stress and maternal behavior, consistent with our earlier hypothesis. Fortunately, although the developing brain is vulnerable to the effects of poverty, neuroscience tells us that the brain can change in response to positive environments at any age.

Cerebral Cortex and Localization of Function

The **cerebral cortex** plays an extremely important role in human cognition. It enables us to think. Because of it, we can plan, coordinate thoughts and actions, perceive visual and sound patterns, and use language. Without it, we would not be human. The cerebral cortex forms a 1- to 3-millimeter layer that wraps the surface of the brain somewhat like the bark of a tree wraps around the trunk. In human beings, the many convolutions, or creases, of the cerebral cortex include three elements. *Sulci* (singular: sulcus) are small grooves. *Fissures* are large grooves. And *gyri* (singular: gyrus) are bulges between adjacent sulci or fissures. These folds greatly increase the surface area of the cortex. If the wrinkly human cortex were smoothed out, it would take up about 2 square feet. The cortex makes up 80% of the human brain (Kolb & Whishaw, 1990).

The volume of the human skull has more than doubled over the past 2 million years, allowing for the expansion of the brain, and especially the cortex (Toro et al., 2008). The surface of the cerebral cortex is grayish (see also Figure 2.1). It is sometimes referred to as *gray matter* because it primarily includes the grayish neural-cell bodies that process the information that the brain receives and sends. In contrast, the underlying *white matter* of the brain's interior includes mostly white, myelinated axons.

The cerebral cortex forms the outer layer of the two halves of the brain—the left and right cerebral hemispheres (Davidson & Hugdahl, 1995; Galaburda & Rosen, 2003; Gazzaniga & Hutsler, 1999; Levy, 2000). Although the two hemispheres appear to be similar, they function differently. The left cerebral hemisphere is specialized for some kinds of activity, whereas the right cerebral hemisphere is specialized for other kinds. For example, receptors in the skin on the right side of the body generally send information through the medulla to areas in the left hemisphere in the brain. The receptors on the left side generally transmit information to the right hemisphere. Similarly, the left hemisphere of the brain directs the motor responses on the right side of the body. The right hemisphere directs responses on the left side of the body.

Not all information transmission is **contralateral**—from one side to another (*contra-*, "opposite"; *lateral*, "side"). Some **ipsilateral** transmission—on the same side—occurs as well. For example, odor information from the right nostril goes primarily to the right side of the brain. About half the information from the right eye goes to the right side of the brain; the other half goes to the left side of the brain. In addition to this general tendency for contralateral specialization, the hemispheres also communicate directly with one another. The **corpus callosum** is a dense aggregate of neural fibers connecting the two cerebral hemispheres (Witelson, Kigar, & Walter, 2003). It transmits information back and forth. Once information has reached one hemisphere, the corpus callosum transfers it to the other hemisphere. If the corpus callosum is cut, the two **cerebral hemispheres**—the two halves of the brain—cannot communicate with each other (Glickstein & Berlucchi, 2008). Although some functioning, such as language, is highly lateralized, most functioning—even language—depends in large part on integration of the two hemispheres of the brain. ■ See Lab14, Brain Asymmetry, in CogLab.

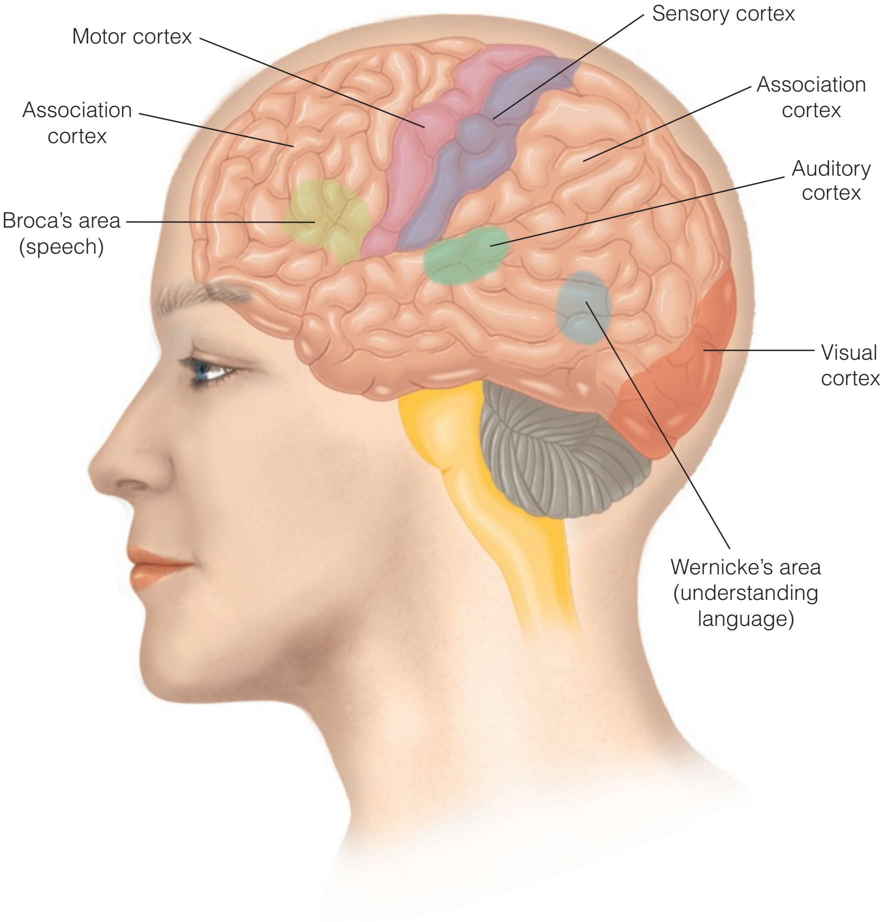
Hemispheric Specialization

How did psychologists find out that the two hemispheres have different responsibilities? The study of hemispheric specialization in the human brain can be traced back to Marc Dax, a country doctor in France. By 1836, Dax had treated more than 40 patients suffering from *aphasia*—loss of speech—as a result of brain damage. Dax noticed a relationship between the loss of speech and the side of the brain in which damage had occurred. In studying his patients' brains after death, Dax saw that in every case there had been damage to the left hemisphere of the brain. He was not able to find even one case of speech loss resulting from damage to the right hemisphere only.

In 1861, French scientist Paul Broca (1824–1880) claimed that an autopsy revealed that an aphasic stroke patient had a lesion in the left cerebral hemisphere of the brain. By 1864, Broca was convinced that the left hemisphere of the brain is critical in speech, a view that has held up over time. The specific part of the brain that Broca identified, now called *Broca's area*, contributes to speech (Figure 2.4 ■).

Another important early researcher, German neurologist Carl Wernicke, studied language-deficient patients who could speak but whose speech made no sense. Like Broca, he traced language ability to the left hemisphere. He studied a different precise location, now known as *Wernicke's area*, which contributes to language comprehension (Figure 2.4).

Karl Spencer Lashley, often described as the father of neuropsychology, started studying localization in 1915. He found that implantations of crudely built electrodes in apparently identical locations in the brain yielded different results. Different locations sometimes paradoxically yielded the same results (e.g., see Lashley, 1950). Subsequent researchers, using more sophisticated electrodes and measurement procedures, have found that specific locations do correlate with specific motor responses across many test sessions. Apparently, Lashley's research was limited by the technology available to him at the time.



■ **Figure 2.4 Functional Areas of the Cortex.** Strangely, although people with lesions in Broca's area cannot speak fluently, they can use their voices to sing or shout.

Source: Adapted from *Psychology: In Search of the Human Mind* by Robert J. Sternberg, 2000 by Harcourt Brace & Company.

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Despite the valuable early contributions by Broca, Wernicke, and others, the individual most responsible for modern theory and research on hemispheric specialization was Nobel Prize–winning psychologist Roger Sperry. Sperry (1964) argued that each hemisphere behaves in many respects like a separate brain. In a classic experiment that supports this contention, Sperry and his colleagues severed the corpus callosum connecting the two hemispheres of a cat's brain. They then proved that information presented visually to one cerebral hemisphere of the cat was not recognizable to the other hemisphere. Similar work on monkeys indicated the same discrete performance of each hemisphere (Sperry, 1964).

Some of the most interesting information about how the human brain works, and especially about the respective roles of the hemispheres, has emerged from studies of humans with epilepsy in whom the corpus callosum has been severed. Surgically severing this neurological bridge prevents epileptic seizures from spreading from one hemisphere to another. This procedure thereby drastically reduces the severity of the seizures. However, this procedure also results in a loss of communication between the two hemispheres. It is as if the person has two separate specialized brains processing different information and performing separate functions. Patients who have undergone an operation severing the corpus callosum are called **split-brain patients**.

Split-brain research reveals fascinating possibilities regarding the ways we think. Many in the field have argued that language is localized in the left hemisphere. Spatial visualization ability (i.e., the ability to mentally manipulate two- or three-dimensional objects) appears to be largely localized in the right hemisphere (Farah, 1988a, 1988b; Gazzaniga, 1985). Spatial-orientation tasks also seem to be localized in the right hemisphere (Vogel, Bowers, & Vogel, 2003). It appears that roughly 90% of the adult population has language functions that are predominantly localized within the left hemisphere. There are indications, however, suggesting that the lateralization of left-handers differs from that of right-handers, and that for females, the lateralization may not be as pronounced as for males (Vogel, Bowers, & Vogel, 2003). More than 95% of right-handers and about 70% of left-handers have left-hemisphere dominance for language. In people who lack left-hemisphere processing, language development in the right hemisphere retains phonemic and semantic abilities, but it is deficient in syntactic competence (Gazzaniga & Hutsler, 1999).

The left hemisphere is important not only in language but also in movement. People with *apraxia*—disorders of skilled movements—often have had damage to the left hemisphere. These people have lost the ability to carry out familiar purposeful movements such as forming letters when writing by hand (Gazzaniga & Hutsler, 1999; Heilman, Coenen, & Kluger, 2008). Another role of the left hemisphere is to examine past experiences to find patterns. Finding patterns is an important step in the generation of hypotheses (Wolford, Miller, & Gazzaniga, 2000).

The right hemisphere is largely "mute" (Levy, 2000). It has little grammatical or phonetic understanding. But it does have good semantic knowledge. It also is involved in practical language use. People with right-hemisphere damage tend to have deficits in following conversations or stories. They also have difficulties in making inferences from context and in understanding metaphorical or humorous speech (Levy, 2000). The right hemisphere also plays a primary role in self-recognition. In particular, the right hemisphere seems to be responsible for identifying one's own face (Platek et al., 2004).

In studies of split-brain patients, the patient is presented with a composite photograph that shows a face that is made up of the left and right side of the faces of two different persons (Figure 2.5 ■). They are typically unaware that they saw conflicting information in the two halves of the picture. When asked to give an answer about what they saw in words, they report that they saw the image in the right half of the picture. When they are asked to use the fingers of the left hand (which contralaterally sends and receives information to and from the right hemisphere) to point to what they saw, participants choose the image from the left half of the picture. Recall the contralateral association between hemisphere and side of the body. Given this association, it seems that the left hemisphere is controlling their verbal processing (speaking) of visual information. The right hemisphere appears to control spatial processing (pointing) of visual information. Thus, the task that the participants are asked to perform is crucial in determining what image the participant thinks was shown.

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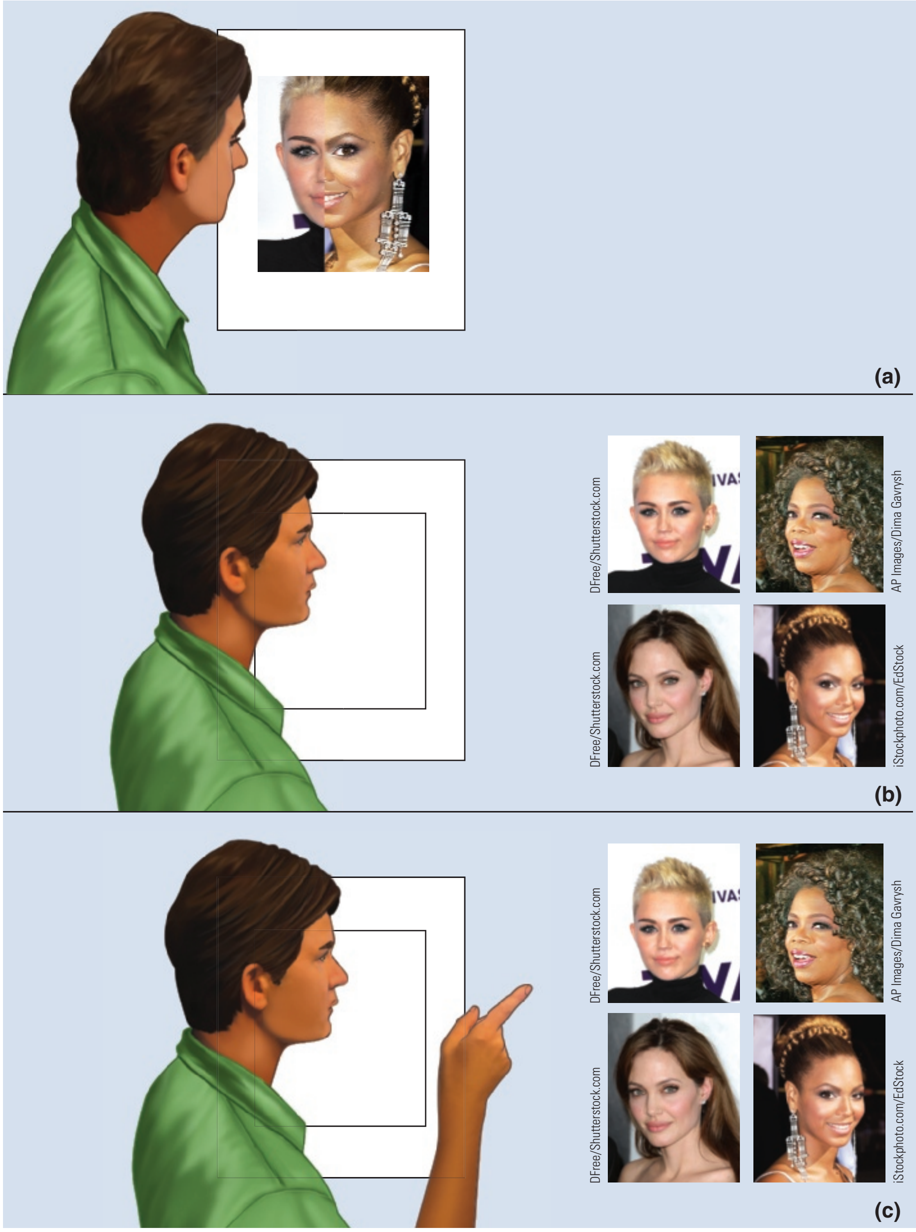
Gazzaniga (Gazzaniga & LeDoux, 1978) does not believe that the two hemispheres function completely independently but rather that they serve complementary roles. For instance, there is no language processing in the right hemisphere (except in rare cases of early brain damage to the left hemisphere). Rather, only visuospatial processing occurs in the right hemisphere. As an example, Gazzaniga has found that before split-brain surgery, people can draw three-dimensional representations of cubes with each hand (Gazzaniga & LeDoux, 1978). After surgery, however, they can draw a reasonable-looking cube only with the left hand. In each patient, the right hand draws pictures unrecognizable either as cubes or as three-dimensional objects. This finding is important because of the contralateral association between each side of the body and the opposite hemisphere



■ **Figure 2.5 A Study with Split-Brain Patients.** In one study, the participant is asked to focus his or her gaze on the center of the screen. Then a chimeric face (a face showing the left side of the face of one person and the right side of another) is flashed on the screen. The participant then is asked to identify what he or she saw, either by speaking or by pointing to one of several normal (not chimeric) faces.

Madonna: Dino de Laurentiis/The Kobal Collection/The Picture Desk; Oprah Winfrey: Dima Gavrysh/
AP Photo; Angelina Jolie: w38/Zuma/Photoshot; Cher: The Kobal Collection/The Picture Desk

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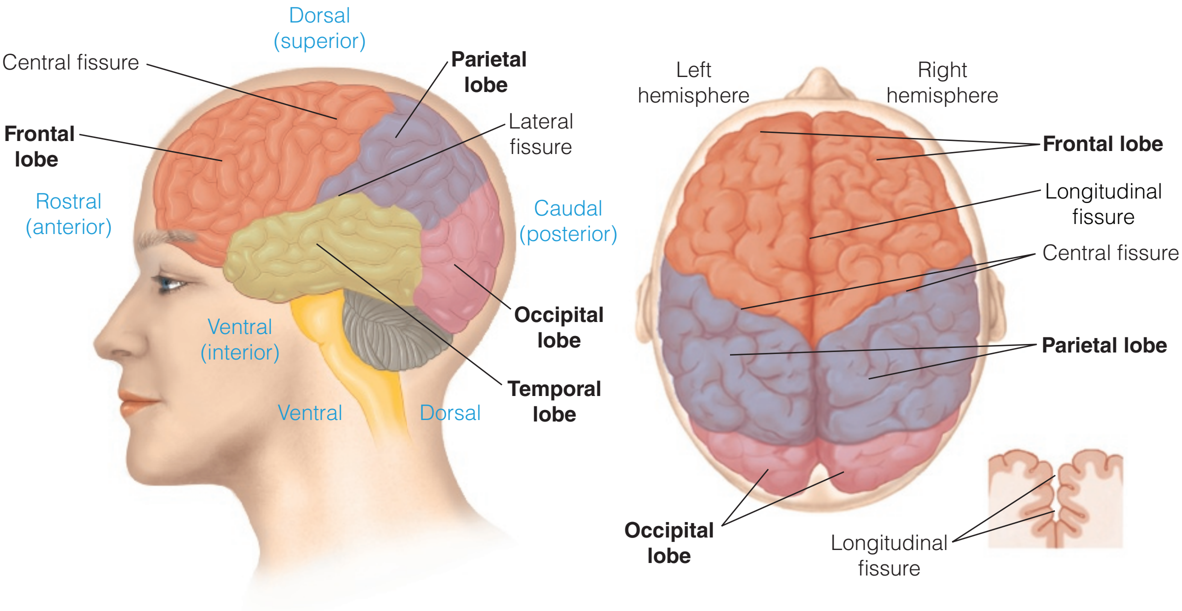
of the brain. Recall that the right hemisphere controls the left hand. The left hand is the only one that a split-brain patient can use for drawing recognizable figures. This experiment thus supports the contention that the right hemisphere is dominant in our comprehension and exploration of spatial relations.

Gazzaniga (1985, 2011) has argued that the brain, and especially the right hemisphere of the brain, is organized into relatively independent functioning units that work in parallel. According to Gazzaniga, each of the many discrete units of the mind operates relatively independently of the others. These operations are often outside of conscious awareness. Although these various independent and often subconscious operations are taking place, the left hemisphere tries to assign interpretations to these operations. Sometimes the left hemisphere perceives that the individual is behaving in a way that does not intrinsically make any particular sense. For example, if you see an adult staggering along a sidewalk at night in a way that does not initially make sense, you may conclude he is drunk or otherwise not in full control of his senses. The brain thus finds a way to assign some meaning to that behavior.

In addition to studying hemispheric differences in language and spatial relations, researchers have tried to determine whether the two hemispheres think in ways that differ from one another. Levy (1974) has found some evidence that the left hemisphere tends to process information analytically (piece-by-piece, usually in a sequence). She argues that the right hemisphere tends to process it holistically (as a whole).

Lobes of the Cerebral Hemispheres

The cerebral hemispheres and cortex can be divided into four parts. They are not distinct units. Rather, they are largely arbitrary anatomical regions divided by fissures. Particular functions have been identified with each lobe, but the **lobes** also interact. The four lobes,


Dorsal (superior)
Central fissure
Parietal lobe
Frontal lobe
Lateral fissure
Rostral (anterior)
Caudal (posterior)
Occipital lobe
Ventral (interior)
Temporal lobe
Ventral
Dorsal
Left hemisphere
Right hemisphere
Frontal lobe
Longitudinal fissure
Central fissure
Parietal lobe
Occipital lobe
Longitudinal fissure

(a) Anatomical areas (left lateral view)

(b) Anatomical areas (top view)

■ **Figure 2.6** **Four Lobes of the Brain.** The cortex is divided into the frontal, parietal, temporal, and occipital lobes. The lobes have specific functions but also interact to perform complex processes.

Source: Adapted from *Psychology: In Search of the Human Mind* by Robert J. Sternberg, 2000 by Harcourt Brace & Company.

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named after the bones of the skull lying directly over them (Figure 2.6 ■), are the frontal, parietal, temporal, and occipital lobes. The lobes are involved in numerous functions. Our discussion of them here describes only part of what they do.

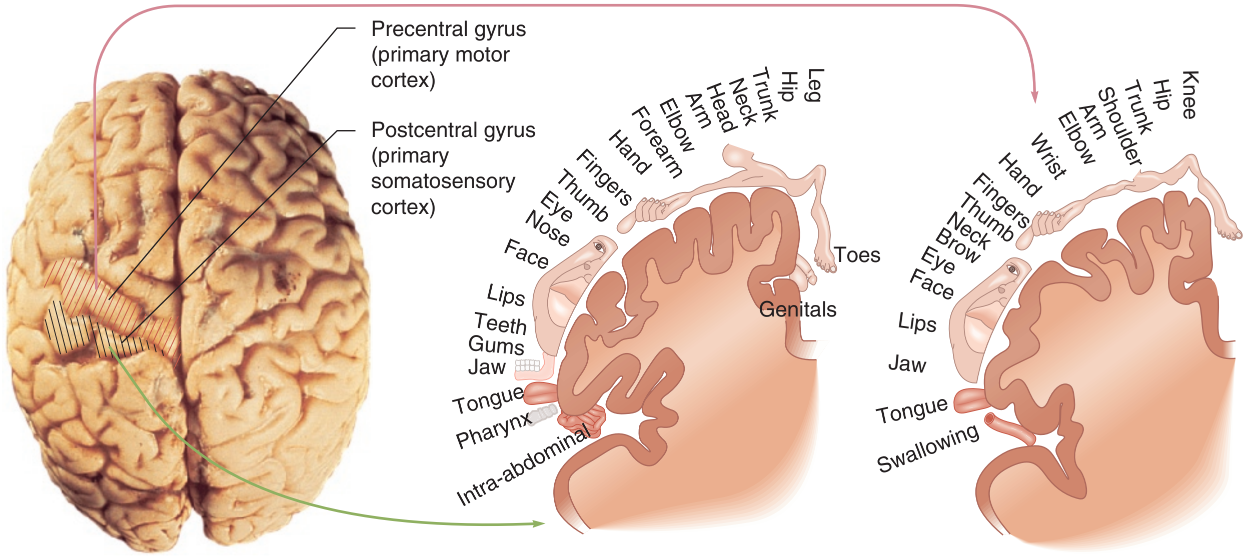
The **frontal lobe**, toward the front of the brain, is associated with motor processing and higher thought processes, such as abstract reasoning, problem solving, planning, and judgment (Stuss & Floden, 2003). It tends to be involved when sequences of thoughts or actions are called for. It is critical in producing speech. The *prefrontal cortex*, the region toward the front of the frontal lobe, is involved in complex motor control and tasks that require integration of information over time (Gazzaniga, Ivry, & Mangun, 2013).

The frontal lobe contains the **primary motor cortex**, which specializes in the planning, control, and execution of movement, particularly of movement involving any kind of delayed response. If your motor cortex were electrically stimulated, you would react by moving a corresponding body part. The nature of the movement would depend on where in the motor cortex your brain had been stimulated. Control of the various kinds of body movements is located contralaterally on the primary motor cortex. A similar inverse mapping occurs from top to bottom. The lower extremities of the body are represented on the upper (toward the top of the head) side of the motor cortex, and the upper part of the body is represented on the lower side of the motor cortex.

Information going to neighboring parts of the body also comes from neighboring parts of the motor cortex. Thus, the motor cortex can be mapped to show where, and in what proportions, different parts of the body are represented in the brain (Figure 2.7 ■). Maps of this kind are called *homunculi* (homunculus is Latin for "little person") because they depict the body parts of a person mapped on the brain.

The three other lobes are located farther away from the front of the head. These lobes specialize in sensory and perceptual activity.

The **parietal lobe**, at the upper back portion of the brain, is associated with somatosensory processing. The **primary somatosensory cortex** receives information from the



(a) Somatosensory cortex **(b) Motor cortex**

■ **Figure 2.7 Homunculus of the Primary Motor Cortex.** This map of the primary motor cortex is often termed a homunculus (from Latin, "little person") because it is drawn as a cross section of the cortex surrounded by the figure of a small upside-down person whose body parts map out a proportionate correspondence to the parts of the cortex.

Source: Based on Kalat, *Biological Psychology* 11e, Figure 4.24, page 1093.

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senses about pressure, texture, temperature, and pain. It is located right behind the frontal lobe's primary motor cortex. If your somatosensory cortex were electrically stimulated, you probably would report feeling as if you had been touched. The parietal lobe also helps you perceive space and your relationship to it—how you are situated relative to the space you are occupying (Culham, 2003; Gazzaniga, Ivry, & Mangun, 2013). It is also involved in consciousness and paying attention. If you are paying attention to what you are reading, your parietal lobe is activated.

From looking at the homunculus (see Figure 2.7), you can see that the relationship of function to form applies in the development of the motor cortex. The same holds true for the somatosensory cortex regions. The greater need we have for use, sensitivity, and fine control in a particular body part, the larger the area of cortex generally devoted to that part. For example, we humans are tremendously reliant on our hands and faces in our interactions with the world. We show correspondingly large proportions of the cerebral cortex devoted to sensation in, and motor response by, our hands and face. Conversely, we rely relatively little on our toes for both movement and information gathering. As a result, the toes represent a relatively small area on both the primary motor and somatosensory cortices.

The **temporal lobe** is located below the parietal lobe, directly under your temples. It is associated with auditory processing (Han et al., 2011; Murray, 2003) and comprehending language. Some parts are more sensitive to sounds of higher pitch, others to sounds of lower pitch. The auditory region is primarily contralateral. Both sides of the auditory area have at least some representation from each ear. If your auditory cortex were stimulated electrically, you would report having heard some sort of sound.

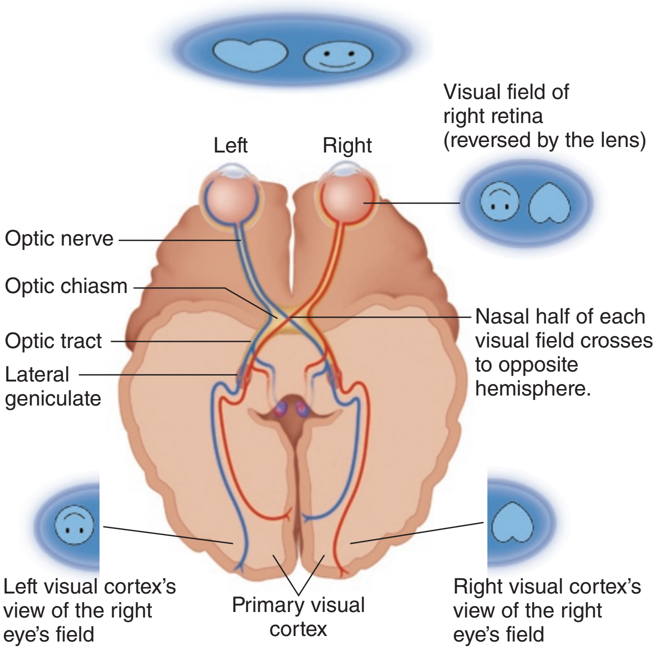
The temporal lobe is also involved in retaining visual memories. For example, if you are trying to keep in memory Figure 2.6, then your temporal lobe is involved. The temporal lobe also matches new things you see to what you have retained in visual memory.

The **occipital lobe** is associated with visual processing (De Weerd, 2003b). The occipital lobe contains numerous visual areas, each specialized to analyze specific aspects of a scene, including color, motion, location, and form (Gazzaniga, Ivry, & Mangun, 2013). When you go to pick strawberries, your occipital lobe helps you find the red strawberries in between the green leaves.

Projection areas are the areas in the lobes in which sensory processing occurs. These areas are referred to as projection areas because the nerves contain sensory information going to (projecting to) the thalamus. It is from here that the sensory information is communicated to the appropriate area in the relevant lobe. Similarly, the projection areas communicate motor information downward through the spinal cord to the appropriate muscles via the peripheral nervous system (PNS).

The **visual cortex** is primarily in the occipital lobe. Some neural fibers carrying visual information travel ipsilaterally from the left eye to the left cerebral hemisphere and from the right eye to the right cerebral hemisphere. Other fibers cross over the *optic chiasma* (from Greek, "visual X" or "visual intersection") and go contralaterally to the opposite hemisphere (Figure 2.8 ■). In particular, neural fibers go from the left side of the visual field for each eye to the right side of the visual cortex. Complementarily, the nerves from the right side of each eye's visual field send information to the left side of the visual cortex.

The brain is a complex structure, and researchers use a variety of expressions to describe which part of the brain they are speaking of. Figure 2.6 explains some other words that are frequently used to describe different brain regions. These are the words *rostral*, *ventral*, *caudal*, and *dorsal*. They are all derived from Latin words and indicate the part of the brain with respect to other body parts.



■ **Figure 2.8 The Optic Tract and Pathways to the Primary Visual Cortex.** Some nerve fibers carry visual information ipsilaterally from each eye to each cerebral hemisphere; other fibers cross the optic chiasma and carry visual information contralaterally to the opposite hemisphere.

Source: Adapted from *Psychology: In Search of the Human Mind* by Robert J. Sternberg, 2000 by Harcourt Brace & Company.

- *Rostral* refers to the front part of the brain (literally the "nasal region").
- *Ventral* refers to the bottom surface of the body/brain (the side of the stomach).
- *Caudal* literally means "tail" and refers to the back part of the body/brain.
- *Dorsal* refers to the upside of the brain (it literally means "back," and in animals the back is on the upside of the body).

The brain typically makes up only one-fortieth of the weight of an adult human body. Nevertheless, it uses about one-fifth of the circulating blood, one-fifth of the available glucose, and one-fifth of the available oxygen. It is the supreme organ of cognition. Understanding both its structure and function, from the neural to the cerebral levels of organization, is vital to an understanding of cognitive psychology. The recent development of the field of cognitive neuroscience, with its focus on localization of function, reconceptualizes the mind–body question discussed in the beginning of this chapter. The question has changed from "Where is the mind located in the body?" to "Where are particular cognitive operations located in the nervous system?" Throughout the text, we return to these questions in reference to particular cognitive operations and discuss these operations in more detail.

Neuronal Structure and Function

To understand how the entire nervous system processes information, we need to examine the structure and function of the cells that constitute the nervous system. Individual neural cells, called **neurons**, transmit electrical signals from one location to another in the nervous system (Carlson, 2006; Shepherd, 2004). The greatest concentration of neurons is in the neocortex of the brain. The neocortex is the part of the brain associated with complex cognition. It is also the part of the cerebral cortex that evolved most recently. This tissue can contain as many as 100,000 neurons per cubic millimeter (Churchland & Sejnowski, 2004). The neurons tend to be arranged in the form of networks, which

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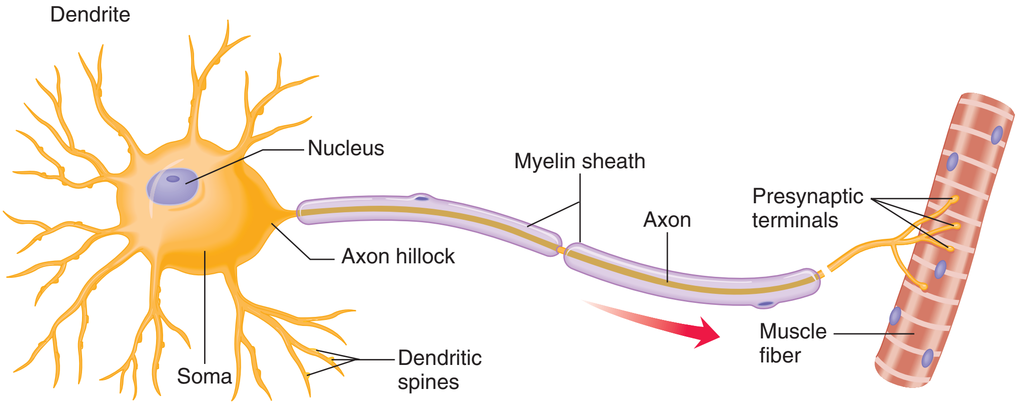

■ **Figure 2.9** **The Composition of a Neuron.** The image shows a neuron with its various components. The information arrives at the dendrites and then is transferred through the axon to the terminal buttons.

provide information and feedback to each other within various kinds of information processing (Vogels, Rajan, & Abbott, 2005).

Neurons vary in their structure, but almost all neurons have four basic parts, as illustrated in Figure 2.9 ■. These include a soma (cell body), dendrites, an axon, and terminal buttons.

The **soma** contains the nucleus of the cell (the center portion that performs metabolic and reproductive functions for the cell). It is responsible for the life of the neuron and connects the dendrites to the axon. The **dendrites** are branchlike structures that receive information from other neurons, and the soma integrates the information. Learning is associated with the formation of new neuronal connections. The **axon** is a long, thin tube that extends (and sometimes splits) from the soma and responds to the information, when appropriate, by transmitting an electrochemical signal, which travels to the terminus (end), where the signal can be transmitted to other neurons.

Axons are of two basic, roughly equally occurring kinds, distinguished by the presence or absence of myelin. **Myelin** is a white, fatty substance that surrounds some of the axons of the nervous system, which accounts for some of the whiteness of the white matter of the brain. The more an axon is myelinated, the faster signals can be transmitted – the speed can reach 100 meters per second (equal to about 224 miles per hour). The myelin is distributed in segments broken up by nodes of Ranvier. **Nodes of Ranvier** are small gaps in the myelin coating along the axon, which increase conduction speed even more by helping to create electrical signals, also called *action potentials*, which are then conducted down the axon. The degeneration of myelin sheaths along axons in certain nerves is associated with multiple sclerosis, an autoimmune disease. It results in impairments of coordination and balance. In severe cases, this disease is fatal.

The **terminal buttons** are small knobs found at the ends of the branches of an axon that do not directly touch the dendrites of the next neuron. Rather, there is a small gap, the synapse. The **synapse** serves as a juncture between the terminal buttons of one or more neurons and the dendrites (or sometimes the soma) of one or more other neurons (Carlson, 2006). Synapses are important in cognition. Rats show increases in both the size and the number of synapses in the brain as a result of learning (Federmeier, Kleim, & Greenough, 2002). Decreased cognitive functioning, as in Alzheimer's disease, is associated with reduced efficiency of synaptic transmission of nerve impulses (Selkoe, 2002). Signal transmission between neurons occurs when the terminal buttons release one or more neurotransmitters at the synapse. **Neurotransmitters** are chemical messengers that transmit information across the synaptic gap to the receiving dendrites of the next neuron (von Bohlen und Halbach & Dermietzel, 2006).

Scientists have identified more than 100 transmitter substances, but it seems likely that more remain to be discovered. Medical and psychological researchers are working to discover and understand neurotransmitters. In particular, they wish to understand how the neurotransmitters interact with drugs, moods, abilities, and perceptions. Although we know much about the mechanics of impulse transmission in nerves, we know relatively little about how the nervous system's chemical activity relates to psychological states. Despite the limits on present knowledge, we have gained some insight into how several of these substances affect our psychological functioning.

Three types of chemical substances appear to be involved in neurotransmission:

- *monoamine neurotransmitters*
- *amino-acid neurotransmitters*
- *neuropeptides*

Acetylcholine is associated with memory functions, and the loss of acetylcholine through Alzheimer's disease has been linked to impaired memory functioning in Alzheimer's patients (Hasselmo, 2006). Acetylcholine also plays an important role in sleep and arousal. When someone awakens, there is an increase in the activity of so-called cholinergic neurons in the basal forebrain and the brainstem (Rockland, 2000)

Dopamine is associated with attention, learning, and movement coordination. Dopamine also is involved in motivational processes, such as reward and reinforcement. Schizophrenics show high levels of dopamine. This fact has led to the "dopamine theory of schizophrenia," which suggests that high levels of dopamine may be partially responsible for schizophrenic conditions. Drugs used to combat schizophrenia often inhibit dopamine activity (von Bohlen und Halbach & Dermietzel, 2006).

In contrast, patients with Parkinson's disease show low dopamine levels, which leads to the typical trembling and movement problems associated with Parkinson's. When patients receive medication that increases their dopamine level, they (as well as healthy people who receive dopamine) sometimes show an increase in pathological gambling. Gambling is a compulsive disorder that results from impaired impulse control. When dopamine treatment is suspended, these patients no longer exhibit this behavior (Abler et al., 2009; Drapier et al., 2006; Voon et al., 2007). These findings support the role of dopamine in motivational processes and impulse control.

Serotonin plays an important role in eating behavior and body-weight regulation. High serotonin levels play a role in some types of anorexia. Specifically, serotonin seems to play a role in the types of anorexia resulting from illness or treatment of illness. For example, patients suffering from cancer or undergoing dialysis often experience a severe loss of appetite (Agulera et al., 2000; Davis et al., 2004). This loss of appetite is related, in both cases, to high serotonin levels. Serotonin is also involved in aggression and regulation of impulsivity (Rockland, 2000). Drugs that block serotonin tend to result in an increase in aggressive behavior.

The preceding description drastically oversimplifies the intricacies of constant neuronal communication. Such complexities make it difficult to understand what is happening in the normal brain when we are thinking, feeling, and interacting with our environment. Many researchers seek to understand the normal information processes of the brain by investigating what is going wrong in the brains of people affected by neurological and psychological disorders. In the case of depression, for example, in the early 1950s a drug (iproniazid, a monoamine oxidase inhibitor) intended to treat tuberculosis was found to have a mood-improving effect. This finding led to some early research on the chemical causes of depression. Perhaps if we can understand what has gone awry—what chemicals are out of balance—we can figure out how processes normally work and how to put things back into balance. One way of doing so might be by providing needed neurotransmitters or by inhibiting the effects of overabundant neurotransmitters.

Receptors in the brain that normally are occupied by the standard neurotransmitters can be hijacked by psychopharmacologically active drugs, legal or illegal. In such cases, the molecules of the drugs enter into receptors that normally would be for neurotransmitter substances endogenous in (originating in) the body.

CONCEPT CHECK

1. Name some of the major structures in each part of the brain (forebrain, midbrain, and hindbrain) and their functions.
2. What does *localization of function* mean?
3. Why do researchers believe that the brain exhibits some level of hemispheric specialization?
4. What are the four lobes of the brain and some of the functions associated with them?
5. How do neurons transmit information?

Viewing the Structures and Functions of the Brain

Scientists can use many methods for observing the human brain and theorizing how it functions. These methods include both *postmortem* studies and *in vivo* techniques. Each technique provides important information about the structure and function of the human brain. Even some of the earliest postmortem studies still influence our thinking about how the brain performs certain functions. The recent trend, however, is to focus on techniques that provide information about human mental functioning as it is occurring. This trend is in contrast to the earlier trend of waiting to find people with disorders and then studying their brains after they died. Because postmortem studies are the foundation for later work, we discuss them first. We then move on to the more modern in vivo techniques.

Postmortem Studies

Postmortem studies and brain dissections have been done for centuries. Even in the twenty-first century, researchers often use dissection to study the relation between the brain and behavior. In the ideal case, studies start during the lifetime of a person. Researchers observe and document the behavior of people who show signs of brain damage while they are alive (Wilson, 2003). Later, after the patients die, the researchers examine the patients' brains for *lesions*—areas where body tissue has been damaged, such as from injury or disease. Then the researchers infer that the lesioned locations may be related to the behavior that was affected. The case of Phineas Gage, discussed in Chapter 1, was explored through these methods.

Through such investigations, researchers may be able to trace a link between an observed type of behavior and anomalies in a particular location in the brain. An early example is Broca's famous patient, Tan (so named because that was the only syllable he was capable of uttering). Tan had severe speech problems. These problems were linked to lesions in an area of the frontal lobe (Broca's area). This area is involved in certain functions of speech production. In more recent times, postmortem examinations of victims of Alzheimer's disease (an illness that causes devastating losses of memory; see Chapter 5) have led researchers to identify some of the brain structures involved in memory (e.g., the hippocampus, described earlier in this chapter). These examinations also have identified some of the microscopic aberrations associated with the disease process (e.g., distinctive tangled fibers in the brain tissue). Although lesioning techniques provide the basic foundation for understanding the relation of the brain to behavior, they are limited in that they cannot be performed on the living brain. As a result, they do not offer insights into more specific physiological processes of the brain. For this kind of information, we need to study live nonhuman animals.

Studying Live Nonhuman Animals

Scientists also want to understand the physiological processes and functions of the living brain. To study the changing activity of the living brain, scientists must use in vivo research. Many early in vivo techniques were performed exclusively on animals. For example, Nobel Prize–winning research on visual perception arose from in vivo studies investigating the electrical activity of individual cells in particular regions of the brains of animals (Hubel & Wiesel, 1963, 1968, 1979; see Chapter 3).

To obtain *single-cell recordings*, researchers insert a thin electrode next to a single neuron in the brain of an animal (usually a monkey or cat). They then record the changes in electrical activity that occur in the cell when the animal is exposed to a stimulus. In this way, scientists can measure the effects of certain kinds of stimuli, such as visually presented lines, on the activity of individual neurons. Neurons fire constantly, even if no stimuli are present, so the researcher must find the stimuli that produce a consistent change in the activity of the neuron. This technique can be used only in laboratory animals, not in humans, because no safe way has yet been devised to perform such recordings in humans.

A second group of animal studies includes selective *lesioning*—surgically removing or damaging part of the brain—to observe resulting functional deficits (Al'bertin, Mulder, & Wiener, 2003; Lee, Rajkumar, & Dawe, 2014; Mohammed, Jonsson, & Archer, 1986). Researchers recently have found neurochemical ways to induce lesions in animals' brains by administering drugs that destroy only those cells that use a particular neurotransmitter. Some drugs' effects are reversible, so that conductivity in the brain is disrupted only for a limited amount of time (Gazzaniga, Ivry, & Mangun, 2013).

A third way of conducting research with animals is by employing genetic knockout procedures. By using genetic manipulations, animals can be created without certain kinds of brain cells or receptors. Comparisons with normal animals then indicate what the function of the missing receptors or cells may be.

Studying Live Humans

Obviously, many of the techniques used to study live animals cannot be used on human participants. Therefore, generalizations to humans based on these studies are somewhat limited. However, an array of less-invasive imaging techniques for use with humans has been developed. These techniques—electrical recordings, static imaging, and metabolic imaging—are described in this section.

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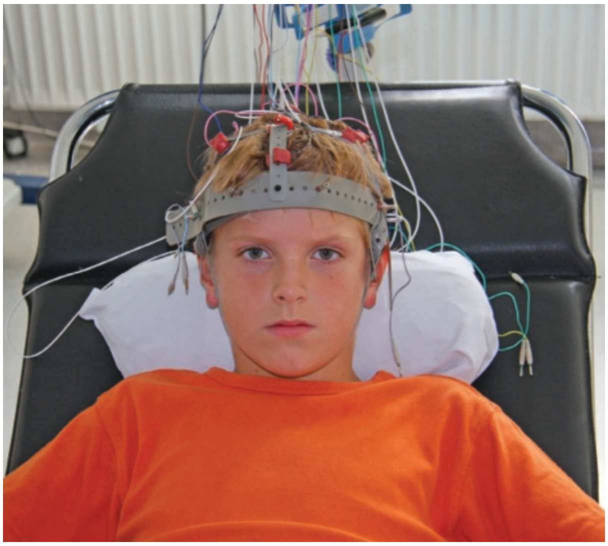
Electrical Recordings

The brain transmits signals through electrical potentials. When recorded, this activity appears as waves of various widths (frequencies) and heights (intensities). **Electroencephalograms (EEGs)** are recordings of the electrical frequencies and intensities of the living brain, typically recorded over relatively long periods (Picton & Mazaheri, 2003). Through EEGs, it is possible to study brainwave activity indicative of changing mental states such as deep sleep or dreaming. To obtain EEG recordings, electrodes are placed at various points along the surface of the scalp. The electrical activity of underlying brain areas is then recorded. The information, therefore, is not localized to specific cells. The EEG is sensitive to changes over time. For example, EEG recordings taken during sleep reveal changing patterns of electrical activity involving the whole brain. Different patterns emerge during dreaming versus deep sleep. EEGs are also used to diagnose epilepsy because they can indicate whether seizures appear in both sides of the brain at the same time, or whether they originate in one part of the brain and then spread.

To relate electrical activity to a particular event or task (e.g., seeing a flash of light or listening to sentences), EEG waves can be measured when participants are exposed to a particular stimulus. An **event-related potential (ERP)** is the record of a small change in the brain's electrical activity in response to a stimulating event. The fluctuation typically lasts a mere fraction of a second. ERPs provide good information about the time-course of task-related brain activity. In any one EEG recording, there is a great deal of "noise"—that is, irrelevant electrical activity going on in the brain. ERPs cancel out the effects of noise by averaging out activity that is not task-related. Therefore, the EEG waves are averaged over a large number (e.g., 100) of trials to reveal the ERPs. The resulting wave forms show characteristic spikes related to the timing of electrical activity, but they reveal only general information about the location of that activity (because of low spatial resolution as a result of the placement of scalp electrodes).

The ERP technique has been used in a wide variety of studies. Some studies of mental abilities such as selective attention have investigated individual differences by using ERPs (e.g., Troche et al., 2009). ERP methods are also used to examine language processing. One study examined children who suffered from developmental language impairment and compared them with those who did not. The children were presented with pictures and a sound or word, and then had to decide whether the picture, on the one hand, and the sound or word, on the other, matched. For example, in a matching pair, a



An EEG.

Marcus Scholz/Fotolia

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picture of a rooster would be presented with either the sound "cock-a-doodle-doo" or the spoken word "crowing." A mismatch would be the picture of the rooster presented with the sound "ding dong" or the spoken word "chiming." There was no difference between the two groups when they had to match the picture with the sound. The children with language impairment had greater difficulty matching the picture with the spoken word. The results confirmed the hypothesis that children with language impairment may have weak language networks (Cummings & Ceponiene, 2010).

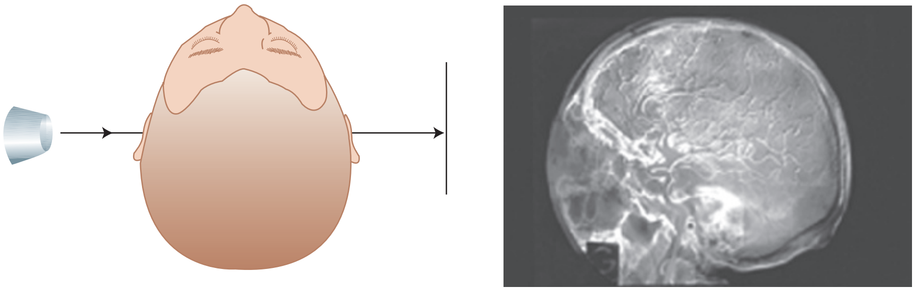
ERP can be used to examine developmental changes in cognitive abilities. These experiments provide a more complete understanding of the relationship between brain and cognitive development (Taylor & Baldeweg, 2002).

The high degree of temporal resolution afforded by ERPs can be used to complement other techniques. For example, ERPs and **positron emission tomography (PET)** were used to pinpoint areas involved in word association (Posner & Raichle, 1994). Using ERPs, the investigators found that participants showed increased activity in certain parts of the brain (left lateral frontal cortex, left posterior cortex, and right insular cortex) when they made rapid associations to given words. As with any technique, EEGs and ERPs provide only a glimpse of brain activity. They are most helpful when used in conjunction with other techniques to identify particular brain areas involved in cognition.

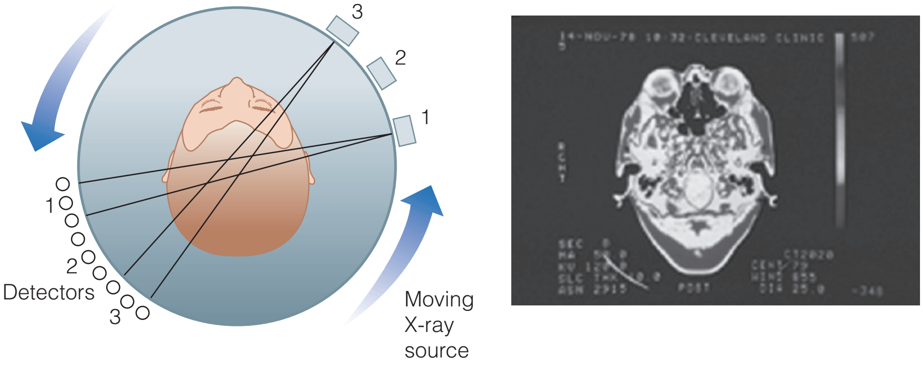
Static Imaging Techniques

Psychologists use still images to reveal the structures of the brain (see Figure 2.10 ■ and Table 2.2 ■). The techniques include computed tomography (CT or CAT) scans, angiograms, and **magnetic resonance imaging (MRI)** scans. X-ray–based techniques

(a) Brain angiogram: A brain angiogram highlights the blood vessels of the brain.



(b) CT scan: A CT image of a brain uses a series of rotating scans to produce a three-dimensional view of brain structures.



Angiogram © CNRI/SPL/Photo Researchers, Inc. CT scan © Ohio Nuclear/SPL/Photo Researchers, Inc.

■ **Figure 2.10 Brain Imaging Techniques.** Various techniques have been developed to picture the structures—and sometimes the processes—of the brain.

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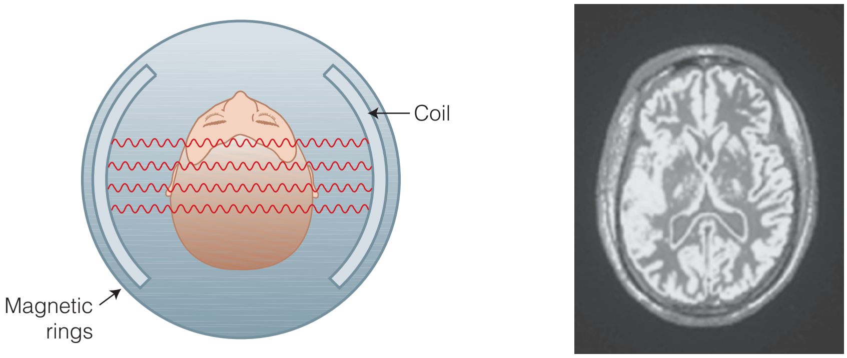
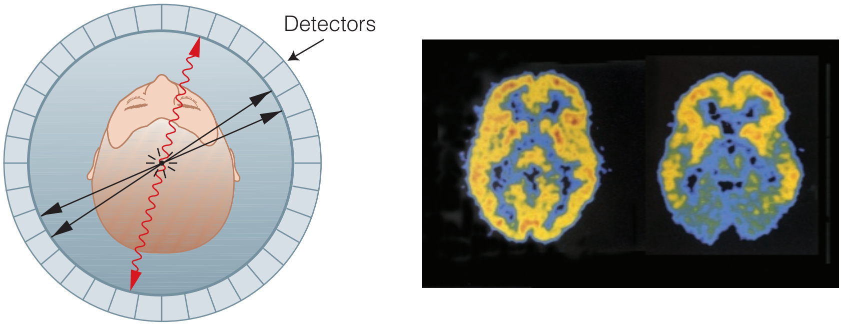
(c) MRI scan: A rotating series of MRI scans shows a clearer three-dimensional picture of brain structures than CT scans show.



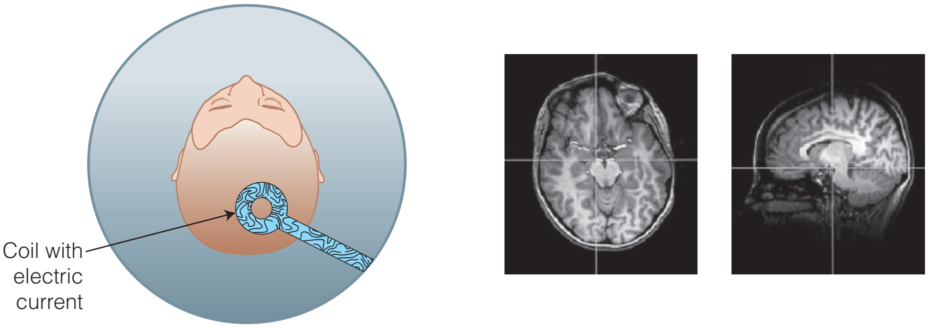
Matthew Bologna/Medical Body Scans/Science Source

(d) PET scan: These still photographs of PET scans of a brain show different metabolic processes during different activities. PET scans permit the study of brain physiology.



Mediscan/Alamy

(e) TMS (Transcranial magnetic stimulation): TMS temporarily disrupts normal brain activity to investigate cognitive functioning when particular areas are disrupted.



Simon Fraser/University of Durham/Science Source

Figure 2.10 Continued

(angiogram and CT scan) allow for the observation of large abnormalities of the brain, such as damage resulting from strokes or tumors. They are limited in their resolution, however, and cannot provide much information about smaller lesions and aberrations.

Unlike conventional X-ray methods that only allow a two-dimensional view of an object, a CT scan consists of several X-ray images of the brain taken from different vantage points that, when combined, result in a three-dimensional image.

The aim of an *angiography* is not to look at the structures in the brain, but rather to examine the blood flow. When the brain is active, it needs energy, which is transported to the brain in the form of oxygen and glucose by means of the blood. In angiography,

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Table 2.2 Cognitive Neuropsychological Methods for Studying Brain Functioning

Method	Procedure	Suitable for Humans?	Advantages	Disadvantages
Single-cell recording	Thin electrode is inserted next to a single neuron. Changes in electrical activity occurring in the cell are then recorded.	No	Rather precise recording of electrical activity	Cannot be used with humans
Electroencephalograms (EEG)	Changes in electrical potentials are recorded via electrodes attached to scalp.	Yes	Relatively noninvasive	Imprecise
Event-related potential (ERP)	Changes in electrical potentials are recorded via electrodes attached to scalp.	Yes	Relatively noninvasive	Does not show actual brain images
Positron emission tomography (PET)	Participants ingest a mildly radioactive form of oxygen that emits positrons as it is metabolized. Changes in concentration of positrons in targeted areas of the brain are then measured.	Yes	Shows images of the brain in action	Less useful for fast processes
Functional magnetic resonance imaging (fMRI)	Creates a magnetic field that induces changes in the particles of oxygen atoms. More active areas draw more oxygenated blood than do less active areas in the brain. The differences in the amounts of oxygen consumed form the basis for fMRI measurements.	Yes	Shows images of the brain in action; more precise than PET	Requires individual to be placed in uncomfortable scanner for some time
Transcranial magnetic stimulation (TMS)	Involves placing a coil on a person's head and then allowing an electrical current to pass through it. The current generates a magnetic field. This field disrupts the small area (usually no more than a cubic centimeter) beneath it. The researcher can then look at cognitive functioning when the particular area is disrupted.	Yes	Enables researcher to pinpoint how disruption of a particular area of brain affects cognitive functioning	Potentially dangerous if misused
Magnetoencephalography (MEG)	Involves measuring brain activity through detection of magnetic fields by placing a device over the head.	Yes	Extremely precise spatial and temporal resolution	Requires expensive machine not readily available to researchers
Functional transcranial Doppler sonography (fTCD)	Ultrasound measures the velocity of blood flow in the brain.	Yes	Excellent temporal resolution, suitable for children	Limited spatial resolution
Near-infrared spectroscopy (NIRS)	A sensor on the forehead measures blood flow in the prefrontal cortex and amount of oxygen in the blood.	Yes	Portable, inexpensive, suitable for children	Instruments need to be finely tuned and sensitive

a dye is injected into an artery that leads to the brain, and then an X-ray image is taken. The image shows the circulatory system, and it is possible to detect strokes (disruption of the blood flow often caused by the blockage of the arteries through a foreign substance) or aneurysms (abnormal ballooning of an artery), or arteriosclerosis (a hardening of arteries that makes them inflexible and narrow).

The MRI scan is of great interest to cognitive psychologists (Figure 2.11 ■). The MRI reveals high-resolution images of the structure of the living brain by computing and analyzing magnetic changes in the energy of the orbits of nuclear particles in the molecules of the body. There are two kinds of MRIs: structural MRIs and functional MRIs. Structural MRIs provide images of the brain's size and shape, whereas functional MRIs visualize the parts of the brain that are activated when a person is engaged in a particular task. MRIs allow for a much clearer picture of the brain than CT scans. A strong magnetic field is passed through the brain of a patient. A scanner detects various patterns of electromagnetic changes in the atoms of the brain. These molecular changes are analyzed by a computer to produce a three-dimensional picture of the brain. This picture includes detailed information about brain structures. For example, MRI has been used to show that musicians who play string instruments such as the violin or the cello tend to have an expansion of the brain in an area of the right hemisphere that controls left-hand movement (because control of hands is contralateral, with the right side of the brain controlling the left hand, and vice versa; Münte, Altenmüller, & Jäncke, 2002). We tend to view the brain as controlling what we can do. This study is a good example of how what we do—our experience—can affect the development of the brain.

MRI also facilitates the detection of lesions, such as lesions associated with particular disorders of language use, but it does not provide much information about physiological processes. The two techniques discussed in the following section, however, do provide such information.

ERproductions Ltd/Blend Images/Getty Images

■ **Figure 2.11** **Magnetic Resonance Imaging (MRI).** An MRI machine can provide data that show which areas of the brain are involved in different kinds of cognitive processing.

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Metabolic Imaging

Metabolic imaging techniques rely on changes that take place within the brain as a result of increased consumption of glucose and oxygen in active areas of the brain (Baars & Gage, 2012). The basic idea is that active areas in the brain consume more glucose and oxygen than do inactive areas during some tasks. An area specifically required by one task ought to be more active during that task than during more generalized processing and thus should require more glucose and oxygen (Purves, Cabeza, Huettel, LaBar, Platt, & Woldorff, 2012). Scientists attempt to pinpoint specialized areas for a task by using the *subtraction method*. This method uses two different measurements: one that was taken while the subject was involved in a more general or control activity, and one that was taken when the subject was engaged in the task of interest. The difference between these two measurements equals the additional activation recorded while the subject is engaged in the target task as opposed to the control task. The subtraction method thus involves subtracting activity during the control task from activity during the task of interest. The resulting difference in activity is analyzed statistically. This analysis determines which areas are responsible for performance of a particular task above and beyond the more general activity. For example, suppose the experimenter wishes to determine which area of the brain is most important for retrieval of word meanings. The experimenter might subtract activity during a task involving reading of words from activity during a task involving the physical recognition of the letters of the words. The difference in activity would be presumed to reflect the additional resources used in retrieval of meaning.

There is one important caveat to remember about these techniques: Scientists have no way of determining whether the net effect of this difference in activity is excitatory or inhibitory (because some neurons are activated by, and some are inhibited by, other neurons' neurotransmitters). Therefore, the subtraction technique reveals net brain activity for particular areas. It cannot show whether the area's effect is positive or negative. Moreover, the method assumes that activation is purely additive—that it can be discovered through a subtraction method without taking into account interactions among elements.

This description greatly oversimplifies the subtraction method. But it shows at a general level how scientists assess physiological functioning of particular areas using imaging techniques.

PET scans measure increases in oxygen consumption in active brain areas during particular kinds of information processing (O'Leary et al., 2007; Raichle, 1998, 1999). To track their use of oxygen, participants are given a mildly radioactive form of oxygen that emits positrons as it is metabolized (positrons are particles that have roughly the same size and mass as electrons, but that are positively rather than negatively charged). Next, the brain is scanned to detect positrons. A computer analyzes the data to produce images of the physiological functioning of the brain in action.

PET scans can assist in the diagnosis of disorders of cognitive decline such as Alzheimer's by searching for abnormalities in the brain (Jack, Barrio, & Kepe, 2013; Patterson et al., 2009). PET scans have been used to show that blood flow increases to the occipital lobe of the brain during visual processing (Nakamura et al., 2000; Posner et al., 1988). PET scans also are used for comparatively studying the brains of people who score high versus low on intelligence tests. When high-scoring people are engaged in cognitively demanding tasks, their brains seem to use glucose more efficiently—in highly task-specific areas of the brain. The brains of people with lower scores appear to use glucose more diffusely, across larger regions of the brain (Haier et al., 1992). Likewise, a study has shown that Broca's area as well as the left anterior temporal area and the cerebellum are involved in the learning of new words (Groenholm et al., 2005).

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PET scans have been used to illustrate the integration of information from various parts of the cortex (Castelli et al., 2005; Posner et al., 1988). Specifically, PET scans were used to study regional cerebral blood flow during several activities involving the reading of single words. When participants looked at a word on a screen, areas of their visual cortex showed high levels of activity. When they spoke a word, their motor cortex was highly active. When they heard a word spoken, their auditory cortex was activated. When they produced words related to the words they saw (requiring high-level integration of visual, auditory, and motor information), the relevant areas of the cortex showed the greatest amount of activity.

PET scans are not highly precise because they require a minimum of about half a minute to produce data regarding glucose consumption. If an area of the brain shows different amounts of activity over the course of time measurement, the activity levels are averaged, potentially leading to conclusions that are less than precise.

Functional magnetic resonance imaging (fMRI) is a neuroimaging technique that uses magnetic fields to construct a detailed representation in three dimensions of levels of activity in various parts of the brain at a given moment in time. This technique builds on MRI, but it uses increases in oxygen consumption to construct images of brain activity. The basic idea is the same as in PET scans, but the fMRI technique does not require the use of radioactive particles. Rather, the participant performs a task while placed inside an MRI machine. This machine typically looks like a tunnel. When someone is wholly or partially inserted in the tunnel, he or she is surrounded by a doughnut-shaped magnet. An fMRI creates a magnetic field that induces changes in the particles of oxygen atoms. More active areas draw more oxygenated blood than do less active areas in the brain. So shortly after a brain area has been active, a reduced amount of oxygen should be detectable in this area. This observation forms the basis for fMRI measurements. These measurements then are computer analyzed to provide the most precise information currently available about the physiological functioning of the brain's activity during task performance.

This technique is less invasive than PET. It also has higher temporal resolution—measurements can be taken for activity lasting fractions of a second, rather than only for activity lasting minutes to hours. One major drawback is the expense of fMRI. Relatively few researchers have access to the required machinery and testing of participants is time consuming.

The fMRI technique can identify regions of the brain active in many areas, such as vision (Engel et al., 1994; Kitada et al., 2010), attention (Cohen et al., 1994; Samanez-Larkin et al., 2009), language (Gaillard et al., 2003; Stein et al., 2009), and memory (Gabrieli et al., 1996; Wolf, 2009). For example, fMRI has shown that the lateral prefrontal cortex is essential for working memory. This is a part of memory that processes information that is actively in use at a given time (McCarthy et al., 1994). Also, fMRI methods are used to examine brain changes in specific patient populations, including people with schizophrenia and epilepsy (Detre, 2004; Weinberger et al., 1996).

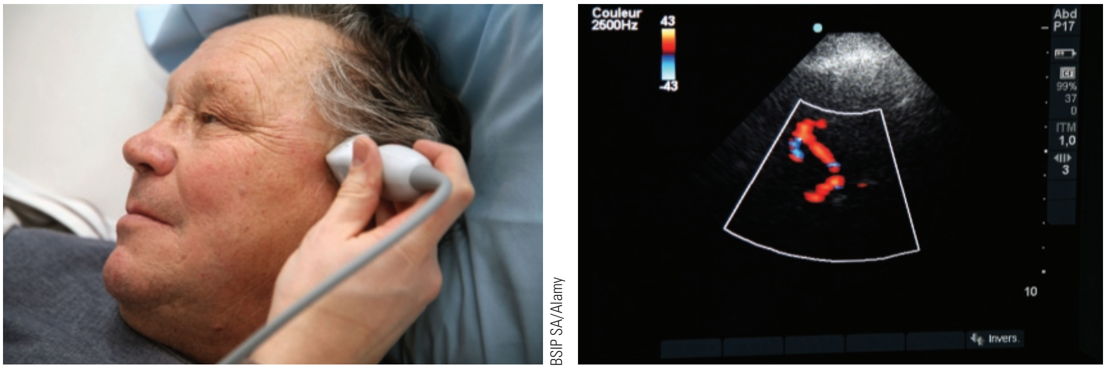
A related procedure is *pharmacological MRI* (phMRI). The phMRI combines fMRI methods with the study of psychopharmacological agents. These studies examine the influence and role of particular psychopharmacological agents on the brain. PhMRIs have been used to examine the role of agonists (which strengthen responses) and antagonists (which weaken responses) on the same receptor cells. These studies have allowed for the examination of drugs used for treatment. The investigators can predict the responses of patients to neurochemical treatments through examination of the person's brain makeup. Overall, these methods aid in the understanding of brain areas and the effects of psychopharmacological agents on brain functioning (Baliki et al., 2005; Easton et al., 2007; Honey & Bullmore, 2004; Kalisch et al., 2004).

Another procedure related to fMRI is *diffusion tensor imaging* (DTI). DTI examines the restricted dispersion of water in tissue and, of special interest, in axons. Water in the brain cannot move freely, but rather, its movement is restricted by the axons and their myelin sheaths. DTI measures how far protons have moved in a particular direction within a specific time interval. This technique has been useful in the mapping of the white matter of the brain and in examining neural circuits. Some applications of this technique include examination of traumatic brain injury, schizophrenia, brain maturation, and multiple sclerosis (Ardekani et al., 2003; Beyer, Ranga, & Krishnan, 2002; Cookey, Bernier, & Tibbo, 2014; Ramachandra et al., 2003; Sotak, 2002; Sundgren et al., 2004).

A recently developed technique for studying brain activity bypasses some of the problems with other techniques (Walsh & Pascual-Leone, 2005). **Transcranial magnetic stimulation (TMS)** temporarily disrupts the normal activity of the brain in a limited area. Therefore, it can imitate lesions in the brain or stimulate brain regions. TMS requires placing a coil on a person's head and then allowing an electrical current to pass through it (Figure 2.10). The current generates a magnetic field. This field disrupts the small area (usually no more than a cubic centimeter) beneath it. The researcher can then look at cognitive functioning when the particular area is disrupted. This method is restricted to brain regions that lie close to the surface of the head. An advantage to TMS is that it is possible to examine causal relationships with this method because the brain activity in a particular area is disrupted and then its influence on task-performance is observed; most other methods allow the investigator to examine only correlational relationships by the observation of brain function (Gazzaniga, Ivry, & Mangun, 2013; Gazzaniga & Mangun, 2014). TMS has been used, for example, to produce "virtual lesions" and investigate which areas of the brain are involved when people grasp or reach for an object (Koch & Rothwell, 2009). It is even hypothesized that repeated magnetic impulses (rTMS) can serve as a therapeutic means in the treatment of neuropsychological disorders such as depression or anxiety disorders (Pallanti & Bernardi, 2009).

Magnetoencephalography (MEG) measures brain activity from outside the head (similar to EEG) by picking up magnetic fields emitted by changes in brain activity. This technique allows localization of brain signals so that it is possible to know what different parts of the brain are doing at different times. It is one of the most precise of the measuring methods. MEG is used to help surgeons locate pathological structures in the brain (Baumgartner, 2000). A recent application of MEG involved patients who reported phantom limb pain. In cases of phantom limb pain, a patient reports pain in a body part that has been removed, for example, a missing foot. When certain areas of the brain are stimulated, phantom limb pain is reduced. MEG has been used to examine the changes in brain activity before, during, and after electrical stimulation. These changes in brain activity corresponded with changes in the experience of phantom limb pain (Kringelbach et al., 2007).

A number of other techniques recently have been developed. One problem that researchers had in the past was that they could locate which parts of the brain are active in a given task by using fMRI and look at the exact timing of processes in the brain using MEG, but it was hard to find a technique that combined the advantages of both techniques. In 2014, researchers at Massachusetts Institute of Technology (MIT) combined the time and location information gained by those two methods by integrating the results using a special computational technique. Thus, in the future, questions about when and where the brain processes visual information will be addressed in more detail (Cichy, Pantazis, & Oliva, 2014).



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Functional transcranial Doppler sonography (fTCD).

Another technology that only recently has been developed is functional transcranial Doppler sonography (fTCD). It uses ultrasound technology to track the velocity of blood flow in the brain. Because the blood flow can be monitored on a continuous basis, the resolution of fTCD is superior to techniques such as PET. It is noninvasive and easy to use, which makes it a good technique to use on children or people who have trouble cooperating with instructions (Lohmann, Ringelstein, & Knecht, 2006).

Near-infrared spectroscopy (NIRS), another technique developed rather recently, can monitor blood flow in the prefrontal cortex. It also can monitor the amount of oxygen in the blood. A sensor is attached to a person's forehead and measurements are taken, usually before, during, and after performing a task. Because attaching the sensor to the forehead is relatively easy and the subject can still move around within limits, this is another technique that works particularly well with children. Also, the instruments are portable for use in a variety of settings.

Current techniques still do not provide unambiguous mappings of particular functions to particular brain structures, regions, or even processes. Rather, some discrete structures, regions, or processes of the brain appear to be involved in particular cognitive functions. Our current understanding of how particular cognitive functions are linked to particular brain structures or processes allows us only to infer suggestive indications of some kind of relationship. Through sophisticated analyses, we can infer increasingly precise relationships. But we are not yet at a point at which we can determine the specific cause–effect relationship between a given brain structure or process and a particular cognitive function because particular functions may be influenced by multiple structures, regions, or processes of the brain. Finally, these techniques provide the best information only in conjunction with other experimental techniques for understanding the complexities of cognitive functioning. These combinations generally are completed with human participants, although some researchers have combined in vivo studies in animals with brain-imaging techniques (Dedeogle et al., 2004; Kornblum et al., 2000; Logothetis, 2004).

Image courtesy of NIRx Medical Technologies

Near-infrared spectroscopy (NIRS).

CONCEPT CHECK

1. In the investigation of the structure and functions of the brain, what methods of study can be used only in nonhuman animals, and what methods can be used in humans?
2. What are typical questions that are investigated with EEGs, PETs, and fMRIs?
3. Why is it useful to have imaging methods that display the metabolism of the brain?
4. What are the advantages and disadvantages of in vivo techniques compared with postmortem studies?

Brain Disorders

A number of brain disorders can impair cognitive functioning. Brain disorders can give us valuable insight into the functioning of the brain. As mentioned previously, scientists often write detailed notes about the condition of a patient and analyze the brain of a patient once the patient has died to see which areas in the brain may have caused the symptoms the patient experienced. Furthermore, with the in vivo techniques that have been developed over the past decades, many tests and diagnostic procedures can be executed during the lifetime of a patient to help ease patient symptoms and to gain new insight into how the brain works.

Stroke

Vascular disorder is a brain disorder caused by a stroke. Strokes occur when the flow of blood to the brain undergoes a sudden disruption. People who experience stroke typically show marked loss of cognitive functioning. The nature of the loss depends on the area of the brain that is affected by the stroke. The person may experience paralysis, pain, numbness, a loss of speech, a loss of language comprehension, impairments in thought processes, a loss of movement in parts of the body, or other symptoms.

Two kinds of stroke may occur (NINDS Stroke Information, 2009). An *ischemic stroke* usually occurs when a buildup of fatty tissue occurs in blood vessels over a period of years, and a piece of this tissue breaks off and gets lodged in arteries of the brain. Ischemic strokes can be treated by clot-busting drugs. The second kind of stroke, a *hemorrhagic stroke*, occurs when a blood vessel in the brain suddenly breaks. Blood then spills into surrounding tissue. As the blood spills over, brain cells in the affected areas begin to die. This death is either from the lack of oxygen and nutrients or from the rupture of the vessel and the sudden spilling of blood. The prognosis for stroke victims depends on the type and severity of damage. Symptoms of stroke appear immediately on the occurrence of stroke.

Typical symptoms include the following (NINDS Stroke Information, 2009):

- numbness or weakness in the face, arms, or legs (especially on one side of the body)
- confusion and difficulty speaking or understanding speech
- vision disturbances in one or both eyes
- dizziness, trouble walking, or loss of balance or coordination
- severe headache with no known cause

BELIEVE IT OR NOT

Brain Surgery Can Be Performed While You Are Awake!

Can you imagine having major surgery performed on you while you are awake? It's possible, and indeed sometimes it is done. When patients who have brain tumors or who suffer from epilepsy receive brain surgery, they are often woken up from the anesthesia after the surgeons have opened their skull and exposed the brain. This way the surgeons can talk to the patient and perform tests by stimulating the patient's brain to map the different areas of the brain that control important functions such as vision or memory. The brain itself lacks pain receptors, and when doctors stimulate a patient's brain during open-brain surgery while the patient is awake, the patient does not feel any pain. You can nevertheless get a headache, but that is because the tissue and nerves that surround the brain are sensitive to pain, not the brain itself. The communication with the patient enhances the safety and precision of the procedure as compared with brain surgery that is performed solely on the basis of brain scans that were performed using imaging technologies discussed in this chapter.

Brain Tumors

Brain tumors, also called *neoplasms*, can affect cognitive functioning in serious ways. Tumors can occur in either the gray or the white matter of the brain. Tumors of the white matter are more common (Gazzaniga, Ivry, & Mangun, 2009).

Two types of brain tumors can occur. Primary brain tumors start in the brain. Most childhood brain tumors are of this type. Secondary brain tumors start as tumors somewhere else in the body, such as in the lungs. Brain tumors can be either benign or malignant. Benign tumors do not contain cancer cells. They typically can be removed and will not grow back. Cells from benign tumors do not invade surrounding cells or spread to other parts of the body. If, however, they press against sensitive areas of the brain, they can result in serious cognitive impairments. They also can be life-threatening, unlike benign tumors in most other parts of the body. Malignant brain tumors, unlike benign ones, contain cancer cells. They are more serious and usually threaten the victim's life. They often grow quickly. They tend to invade surrounding healthy brain tissue. In rare instances, malignant cells may break away and cause cancer in other parts of the body. Following are the most common symptoms of brain tumors (What You Need to Know about Brain Tumors, 2009):

- headaches (usually worse in the morning)
- nausea or vomiting
- changes in speech, vision, or hearing
- problems balancing or walking
- changes in mood, personality, or ability to concentrate
- problems with memory
- muscle jerking or twitching (seizures or convulsions)
- numbness or tingling in the arms or legs

The diagnosis of brain tumor typically is made through neurological examination, CT scan, or MRI. The most common form of treatment is a combination of surgery, radiation, and chemotherapy.

Head Injuries

Head injuries result from many causes, such as a car accident, contact with a hard object, or a bullet wound. Head injuries are of two types. In *closed-head injuries*, the skull

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remains intact, but there is damage to the brain, typically from the mechanical force of a blow to the head. Slamming one's head against a windshield in a car accident might result in such an injury. In *open-head injuries*, the skull does not remain intact but rather is penetrated, for example, by a bullet.

Head injuries are surprisingly common. Roughly 1.4 million North Americans suffer such injuries each year. About 50,000 of them die, and 235,000 need to be hospitalized. About 2% of the U.S. population needs long-term assistance in their daily living because of head injuries (National Center for Injury Prevention and Control, 2009b). Snowboarder Kevin Pearce sustained a traumatic brain injury while training for the 2010 winter Olympic Games in Vancouver. He spent almost a month in intensive care and then spent another three months in hospital rehabilitation, needing to learn again how to walk and speak. His recovery continues even years after the accident. He has shifted his career from snowboarding to educating the public about brain injuries and raising money to improve the lives of those affected by brain injuries.

Loss of consciousness is a sign that there has been some degree of damage to the brain as a result of the injury. Damage resulting from head injury can include spastic movements, difficulty in swallowing, and slurring of speech, among many other cognitive problems. Immediate symptoms of a head injury include the following (National Center for Injury Prevention and Control, 2009a):

- abnormal breathing
- disturbance of speech or vision
- pupils of unequal size
- weakness or paralysis
- dizziness
- neck pain or stiffness

Cognitive symptoms can vary widely, depending on the area of the brain that is affected. Patients may experience concentration problems, may have difficulty understanding others or speaking and putting their own thoughts in words, may find it hard to understand abstract concepts, or may have trouble remembering things.

CONCEPT CHECK

1. Why is the study of brain disorders useful for cognitive psychologists?
2. What are brain tumors, and how are they diagnosed?
3. What are the causes of strokes?
4. What are some of the symptoms of head injuries?

Key Themes

In Chapter 1, we reviewed seven key themes that pervade cognitive psychology. Several of them are relevant here.

Biological versus behavioral methods. The mechanisms and methods described in this chapter are primarily biological. And yet, a major goal of biological researchers is to discover how cognition and behavior relate to these biological mechanisms. For example, they study how the hippocampus enables learning. Thus, biology, cognition,

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and behavior work together. They are not in any way mutually exclusive. They answer related, but not identical, questions (Uttal, 2014).

Nature versus nurture. One comes into the world with many biological structures and mechanisms in place. But nurture acts to develop them and enable them to reach their potential. The existence of the cerebral cortex is a result of nature, but the memories stored in it derive from nurture. As stated in Chapter 1, nature does not act alone. Rather, its marvels unfold through the interventions of nurture.

Applied versus basic research. Much of the research in biological approaches to cognition is basic. But this basic research later enables us, as cognitive psychologists, to make applied discoveries. For example, to understand how to treat and, hopefully, help individuals with brain damage, cognitive neuropsychologists first must understand the nature of the damage and its pervasiveness. Many modern antidepressants, for example, affect the reuptake of serotonin in the nervous system. By inhibiting reuptake, they increase serotonin concentrations and ultimately increase feelings of well-being. Interestingly, applied research can help basic research as much as basic research can help applied research. In the case of antidepressants, scientists knew the drugs worked before they knew exactly how they worked. Applied research in creating the drugs helped the scientists understand the biological mechanisms underlying the success of the drugs in relieving symptoms of depression.

SUMMARY

1. **What are the fundamental structures and processes within the brain?** The nervous system, governed by the brain, is divided into two main parts: the central nervous system, consisting of the brain and the spinal cord, and the peripheral nervous system, consisting of the rest of the nervous system (e.g., the nerves in the face, legs, arms, and viscera).
2. **How do researchers study the major structures and processes of the brain?** For centuries, scientists have viewed the brain by dissecting it. Modern dissection techniques include the use of electron microscopes and sophisticated chemical analyses to probe the mysteries of individual cells of the brain. Additionally, surgical techniques on animals (e.g., the use of selective lesioning and single-cell recording) often are used. On humans, studies have included electrical analyses (e.g., electroencephalograms and event-related potentials), studies based on the use of X-ray techniques (e.g., angiograms and computed tomograms), studies based on computer analyses of magnetic fields within the brain (magnetic resonance imaging), and studies based on computer analyses of blood flow and metabolism within the brain (positron emission tomography and functional magnetic resonance imaging) (Sousa, 2011).
3. **What have researchers found as a result of studying the brain?** The major structures of the brain may be categorized as those in the forebrain (e.g., the all-important cerebral cortex and the thalamus, the hypothalamus, and the limbic system, including the hippocampus), the midbrain (including a portion of the brainstem), and the hindbrain (including the medulla oblongata, the pons, and the cerebellum). The highly convoluted cerebral cortex

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surrounds the interior of the brain and is the basis for much of human cognition. The cortex covers the left and right hemispheres of the brain. They are connected by the corpus callosum. In general, each hemisphere contralaterally controls the opposite side of the body. Based on extensive split-brain research, many investigators believe that the two hemispheres are specialized: In most people, the left hemisphere primarily controls language. The right hemisphere primarily controls visuospatial processing. The two hemispheres also may process information differently.

Another way to view the cortex is to identify differences among four lobes. Roughly speaking, higher thought and motor processing occur in the frontal lobe. Somatosensory processing occurs in the parietal lobe. Auditory processing occurs in the temporal lobe, and visual processing occurs in the occipital lobe. Within the frontal lobe, the primary motor cortex controls the planning, control, and execution of movement. Within the parietal lobe, the primary somatosensory cortex is responsible for sensations in our muscles and skin. Specific regions of these two cortices can be mapped to particular regions of the body.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. How have views of the nature of the relation between brain and cognition changed over time?
2. Briefly summarize the main structures and functions of the brain.
3. What are some of the reasons that researchers are interested in finding out the localization of function in the human brain?
4. In your opinion, why have the hindbrain, the midbrain, and the forebrain evolved (across the human species) and developed (across human prenatal development) in the sequence mentioned in this chapter? Include the main functions of each in your comments.
5. Researchers already are aware that a deficit of a neurotransmitter, acetylcholine, in the hippocampus is linked to Alzheimer's disease. Given the difficulty of reaching the hippocampus without causing other kinds of brain damage, how might researchers try to treat Alzheimer's disease?
6. In your opinion, why is it that some discoveries, such as that of Marc Dax, go unnoticed? What can be done to maximize the possibility that key discoveries will be noticed?
7. Given the functions of each of the cortical lobes, how might a lesion in one of the lobes be discovered?
8. What is an area of cognition that could be studied effectively by viewing the structure or function of the human brain? Describe how a researcher might use one of the techniques mentioned in this chapter to study that area of cognition.

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brainstem, p. 42
cerebellum, p. 42
cerebral cortex, p. 44
cerebral hemispheres, p. 44
cognitive neuroscience, p. 36
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MEDIA RESOURCES

■ CogLab

Explore the following experiment in CogLab:

Lab 14—Brain Asymmetry

Visual Perception

3

CHAPTER OUTLINE

From Sensation to Perception
  Some Basic Concepts of Perception
  Seeing Things That Aren't There, or Are They?
  How Does Our Visual System Work?
  Pathways to Perceive the What and the Where
Approaches to Perception: How Do We Make Sense of What We See?
  Bottom-Up Theories
    Direct Perception
    Template Theories
    Feature-Matching Theories
    Recognition-by-Components Theory
  Top-Down Theories
  How Do Bottom-Up Theories and Top-Down Theories Go Together?
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  Viewer-Centered versus Object-Centered Perception
  The Perception of Groups—Gestalt Laws
  Recognizing Patterns and Faces
    Two Different Pattern Recognition Systems
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The Environment Helps You See
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    The Neuroscience of Depth Perception
Deficits in Perception
  Agnosias and Ataxias
    Difficulties Perceiving the "What"
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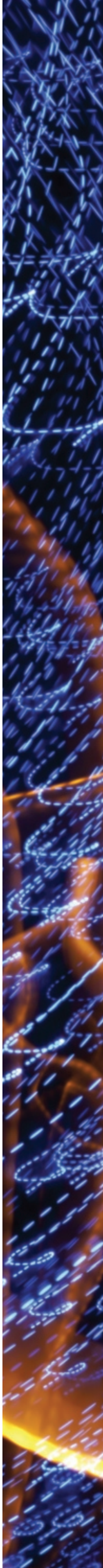
Why Does It Matter? Perception in Practice
Key Themes
Summary
Thinking about Thinking: Analytical, Creative, and Practical Questions
Key Terms
Media Resources

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. How can we perceive an object, such as a chair, as having a stable form given that the image of the chair on our retina changes as we look at it from different directions?
2. What are two fundamental approaches to explaining perception?
3. What happens when people with normal visual sensations cannot perceive visual stimuli?

BELIEVE IT OR NOT

If You Encountered Tyrannosaurus Rex, Would Standing Still Save You?

Have you seen the movie *Jurassic Park*? In this movie, one protagonist tells another while facing a Tyrannosaurus rex that they will be safe as long as they don't move because the T. rex can detect its prey only when it is moving. Well, he could not have been more wrong. As it now turns out, T. rex had excellent binocular vision (i.e., the vision fields of both eyes are combined to achieve depth perception). Researchers had the heads of several dinosaur species reconstructed and found that T. rex probably could see 13 times better than humans (for comparison, eagles can see only 3.6 times better than humans). Its excellent vision is due to the big binocular range, which is the area that can be seen by both eyes at the same time. In addition, over time, T. rex's snout became longer, its cheeks grew thinner so as not to obstruct the view, and its eyeballs became bigger. These changes all helped T. rex to have excellent three-dimensional (3-D) vision (Jaffe, 2006; Stevens, 2006). This chapter will introduce you to the basics of visual perception for humans—and sometimes for other species as well.

As we are writing this chapter, we can look out of the window onto the city of Boston. The high-rise buildings that are less than a mile away look about as small as our computer screen. Yet we know that they are actually much bigger than our screen. They only appear to be small. Try it out yourself. Look out of your window. Can you see how things that are farther away seem much smaller than you know they are? This is just one example of the complex process of perception.

Have you ever been told that you can't see something that's right under your nose? How about that you can't see the forest for the trees? Have you ever listened to your favorite song over and over, trying to decipher the lyrics? In each of these situations, we call on the complex construct of perception. **Perception** is the set of processes by which we recognize, organize, and make sense of the sensations we receive from environmental stimuli (Goodale, 2000a, 2000b; Kosslyn & Osherson, 1995; Marr, 1982; Pomerantz, 2003). When you look at an image in this book, sensory receptors in the retina are being stimulated and your sensation is transmitted to the brain through nerve impulses. Your brain interprets and organizes these sensations and turns them into a perception of a coherent image. Perception encompasses many psychological phenomena. In this chapter, we focus primarily on visual perception. It is the most widely recognized and the most widely studied perceptual modality (i.e., system for a particular sense, such as touch or smell). First, we will get to know a few basic terms and concepts of perception. We will then consider optical illusions that illustrate some of the intricacies of human perception. Next, we examine the biology of the visual system. We will consider some approaches to explain perception and, afterward, have a closer look at some details of the perceptual process, namely the perception of

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objects and forms, and how the environment provides cues to help you perceive your surroundings. We will also explore what happens when people have difficulties in perception.

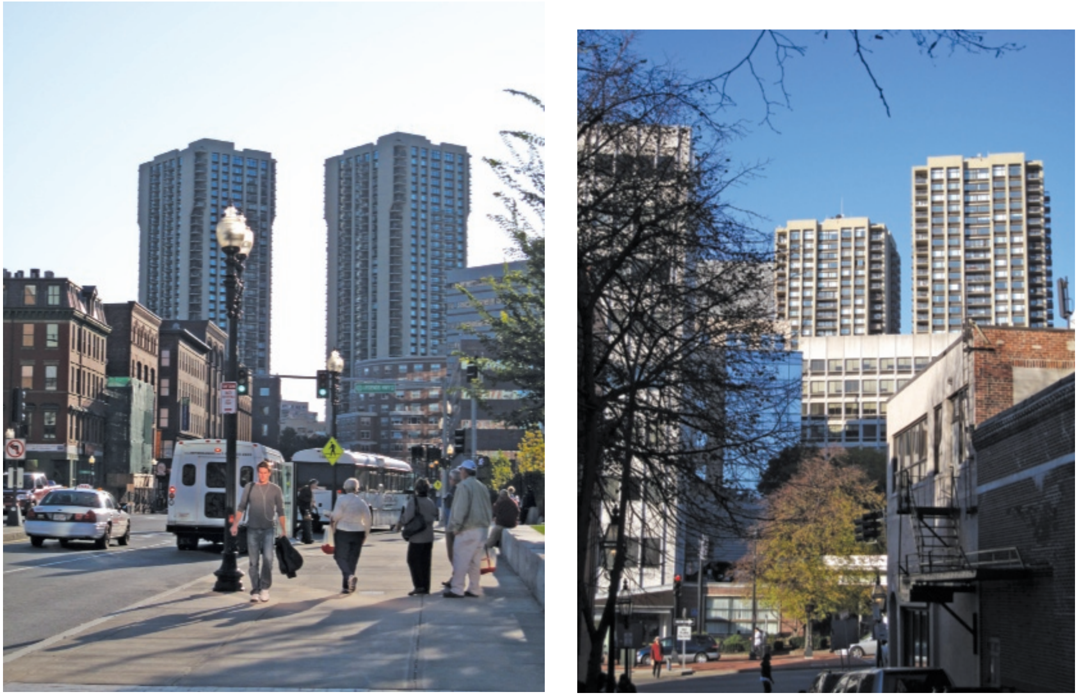
INVESTIGATING COGNITIVE PSYCHOLOGY

Perception

Stand at one end of a room and hold your thumb up to your eye so that it is the same size as the door on the opposite side of the room. Do you *really* think that your thumb is as large as a door? No. You know that your thumb is close to you, so it just *looks* as large as the door. There are numerous cues in the room to tell you that the door is farther away from you than your thumb is. In your mind, you make the door much larger to compensate for the distance away from you. Knowledge is a key to perception. You know that your thumb and the door are not the same size, so you are able to use this knowledge to correct for what you know is not so.

From Sensation to Perception

We do not perceive the world exactly as our eyes see it. Instead, our brain actively tries to make sense of the many stimuli that enter our eyes and fall on our retina. Take a look at Figure 3.1 ■. You can see two high-rise buildings in the city of Boston. (We live in one of them!) In the right photo, the right tower seems to be substantially higher than the


(a) (b)

Courtesy of the author

■ **Figure 3.1 Objects Look Different Depending on the Perspective.** The pictures show the same two high-rise buildings in Boston from two different perspectives. In (a) they look about the same size, as they in fact are. In (b), their image on the retina makes them seem to be of different heights, and it is only through further processing that we can pinpoint they are the same size.

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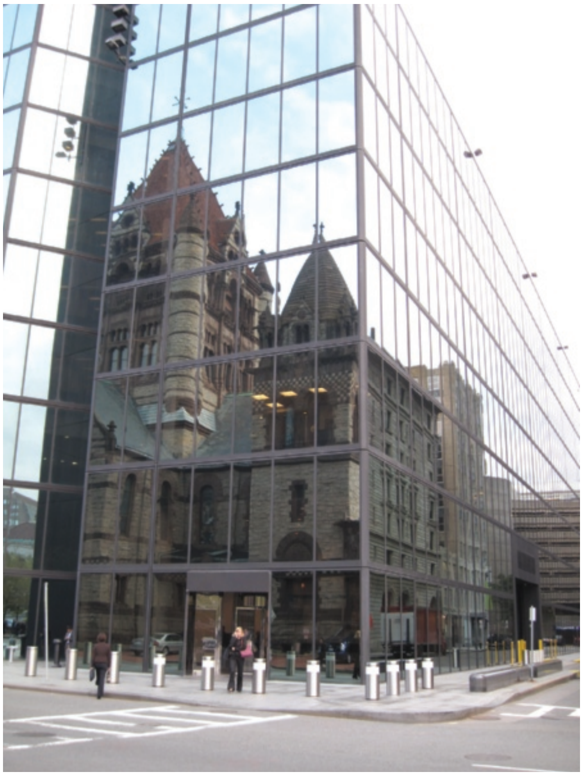

Courtesy of the author

■ **Figure 3.2** **Reality or Reflection?** This picture shows the reflection of a church in a skyscraper. What is easy for us to perceive constitutes a big problem for computers. Where does one building end and the next one start? Which part of the percept belongs to which object? What distinguishes the real person on the street from his or her reflection in the building so that a computer can recognize which one is the reflection?

left one. The left picture, however, shows that the towers actually are in fact exactly the same height. Depending on your viewpoint, objects can look different, revealing different details. Thus, perception does not consist of just seeing what is being projected onto your retina; the process is much more complex. Your brain processes the visual stimuli, giving the stimuli meaning and interpreting them.

In recent years, researchers have tried to teach computers to "see." Although computers still lag behind humans in object recognition, the research showed how difficult it is to interpret visual stimuli, or what we see. Can you recognize what is shown in Figure 3.2 ■? The picture shows the reflection of a church in a high-rise building. It might have taken you a few moments to figure out what is in the photo, but for computers, this is an extremely difficult task. It is not immediately clear in this picture what is reflection, what is the building, and what is surrounding. Furthermore, the borders of the church are blurred so that it becomes challenging to see where the object ends and what it really is. Although it may not take you a lot of effort to identify the objects in this photo, it takes a lot of processing to perceive them, as the stimuli are ambiguous.

This section focuses on the processes of visual perception and the processes we use to make sense of the visual stimuli that are focused on our retina. We start our exploration by familiarizing ourselves with some basic concepts. To illustrate the intricacies of perception, we then look at some optical illusions. And finally we learn how the eye receives impressions of stimuli and sends signals to the brain.

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Some Basic Concepts of Perception

James Gibson (1966, 1979) provided a useful framework for studying perception in his influential work. He introduced the concepts of distal (external) object, informational medium, proximal stimulation, and perceptual object. Let's examine each of these.

The *distal* (far) *object* is the object in the external world (e.g., a falling tree). A tree falling creates a pattern on an *informational medium*. The informational medium could be sound waves, as in the sound of the falling tree or reflected light, chemical molecules, or tactile information coming from the environment. For example, when the information from light waves comes into contact with the appropriate sensory receptors of the eyes, *proximal* (near) *stimulation* occurs (i.e., the cells in your retina absorb the light waves). Perception occurs when a *perceptual object* (i.e., what you see) is created in you that reflects the properties of the external world. That is, an image of a falling tree is created on your retina that reflects the falling tree that is in front of you.

Table 3.1 ■ lists the various properties of distal objects, informational media, proximal stimuli, and perceptual objects for five different senses (sight, sound, smell, taste, and touch). The processes of perception vary tremendously across the different senses.

So, if a tree falls in the forest and no one is around to hear it, does it make a sound? It makes no perceived sound. But it does make a sound by creating sound waves. So the answer is yes or no, depending on how you look at the question. You would answer yes if

Table 3.1 From Sensation to Perception

Perception occurs when the informational medium carries information about a distal object to a person. When the person's sense receptors pick up on the information, proximal stimulation occurs and the person perceives an object.

Modality	Distal Object	Informational Medium	Proximal Stimulation	Perceptual Object
Vision—sight	Grandma's face	Reflected light from Grandma's face (visible electromagnetic waves)	Photon absorption in the rod and cone cells of the retina, the receptor surface in the back of the eye	Grandma's face
Audition—sound	A falling tree	Sound waves generated by the tree's fall	Sound-wave conduction to the basilar membrane, the receptor surface within the cochlea of the inner ear	A falling tree
Olfaction—smell	Bacon being fried	Molecules released by frying bacon	Molecular absorption in the cells of the olfactory epithelium, the receptor surface in the nasal cavity	Bacon
Gustation—taste	Ice cream	Molecules of ice cream both released into the air and dissolved in water	Molecular contact with taste buds, the receptor cells on the tongue and soft palate, combined with olfactory stimulation	Ice cream
Touch	A computer keyboard	Mechanical pressure and vibration at the point of contact between the surface of the skin and the keyboard	Stimulation of various receptor cells within the dermis, the innermost layer of skin	Computer keys

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you believe that the existence of sound waves is all that's needed to confirm the existence of a sound, but you would answer no if you believe the sound needs to be perceived (for the sound waves to have landed on the receptors in someone's ears).

Where does perception end and cognition begin? Furthermore, where does sensation end and perception begin? Answers to both questions are debatable. Instead we should view these processes as part of a continuum. Information flows through the system. Different processes address different questions. Questions of *sensation* focus on qualities of stimulation. Is that shade of red brighter than the red of a Red Delicious apple? Is the sound of that falling tree louder than the sound of thunder? How well do your impressions of color or sound match your friends' impressions of the same?

Perception questions typically relate to identity and form, pattern, and movement. Is that red thing an apple? Did I just hear a tree falling? *Cognition* occurs when this information is used to determine further goals. Is that apple edible? Should I get out of this forest?

We can never see, hear, taste, smell, or feel the exact same set of stimulus properties we experienced before. Every apple casts a somewhat different image on our retina, no falling tree sounds exactly like another, and even the faces of our relatives and friends look different, depending on whether they are smiling, enraged, or sad. And a person's voice sounds somewhat different, depending on whether he or she is sick, out of breath, tired, happy, or sad. Therefore, one fundamental question for perception is "How do we achieve perceptual stability when there is so much instability at the level of sensory receptors?" Given the nature of our sensory receptors, variation is necessary for perception! In *sensory adaptation*, receptor cells adapt to constant stimulation by not firing until there is a change in stimulation. Through sensory adaptation, we may stop detecting the presence of a stimulus.

To study visual perception, scientists devised a way to create stabilized images. Stabilized images do not move across the retina because they follow the eye movements. The use of this technique confirmed the hypothesis that constant stimulation of the cells of the retina gives the impression that the image disappears (Ditchburn, 1980; Martinez-Conde, Macknik, & Hybel, 2004; Riggs et al., 1953).

When your eyes are exposed to a uniform field of stimulation (e.g., a red surface area without any shades, a clear blue sky, or dense fog), you will stop perceiving that stimulus after a few minutes and see just a gray field instead. This is because your eyes have adapted to the stimulus. Such a uniform visual field is called *Ganzfeld*. Ganzfeld is German and means "complete field" (Metzger, 1930).

INVESTIGATING COGNITIVE PSYCHOLOGY

The Ganzfeld Effect

Cut a Ping-Pong ball in two halves or use two plastic spoons. Paint them red, making sure there are no streaks to ensure one uniform field of color. Put the ball halves or the spoons over your eyes so that your eyes are completely covered. Then gaze toward a light source for a few minutes. At some point, your perception will change from the color red to gray because your cells have adapted to the constant stimulus (the red of the ball halves or spoons). This is a Ganzfeld. Some people may perceive hallucinations and experience altered states of consciousness when exposed to a Ganzfeld (Wackermann, Puetz, & Allefeld, 2008).

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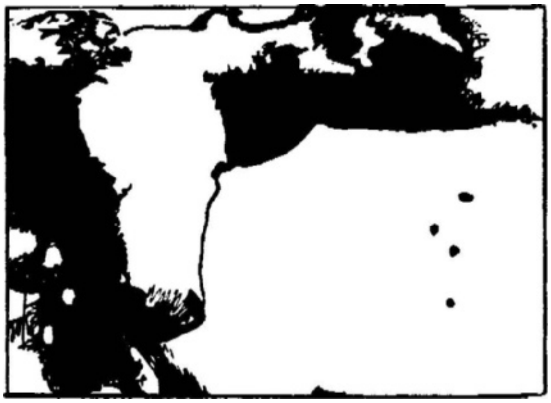
Sensory adaptation ensures that sensory information is changing constantly. Because of the dulling effect of sensory adaptation in the retina (the receptor surface of the eye), our eyes constantly are making tiny rapid movements. These movements create constant changes in the location of the projected image inside the eye. Thus, stimulus variation is an essential attribute for perception. It paradoxically makes the task of explaining perception more difficult. Sensory adaptation also plays a role in other senses. Have you ever been to a hotel room that strongly smelled like smoke when you entered first? After a while, you adapt to the smell and do not notice it anymore, or at least not as much.



■ **Figure 3.3** **Dallenbach's Cow.** What do you learn about your own perception by trying to identify the object staring at you from this photo?

Source: From Dallenbach, K. M. (1951). A puzzle-picture with a new principle of concealment. *American Journal of Psychology, 54,* 431–433.

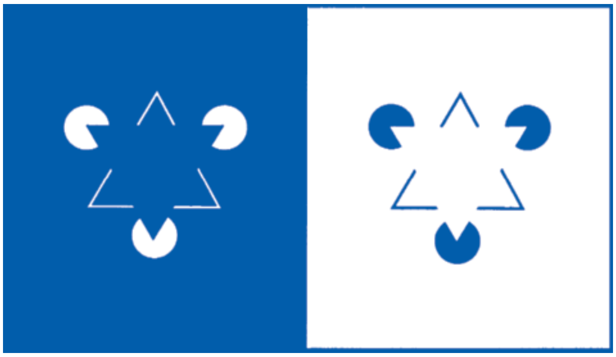
Seeing Things That Aren't There, or Are They?

To expand our knowledge of perception, psychologists often study situations that pose problems in making sense of our sensations. Consider the image displayed in Figure 3.3 ■. To most people, the figure initially looks like a blur of meaningless shadings. A recognizable creature is staring them in the face, but they may not see it. When people finally realize what is in the figure, they rightfully feel "cowed." The figure of the cow is hidden within the continuous gradations of shading that constitute the picture. Before you recognized the figure as a cow, you correctly sensed all aspects of the figure. But you had not yet organized those sensations to form a mental **percept**—a mental representation of a stimulus that is perceived. Without such a percept of the cow, you could not meaningfully grasp what you previously had sensed.

The preceding examples show that sometimes we cannot perceive things that exist. At other times, however, we perceive things that do not exist. For example, notice the blue triangle in the center of the left panel of Figure 3.4 ■. Also note the white triangle in the center of the right panel of Figure 3.4. They jump right out at you. Now look closely at each of the panels. You will see that the triangles are not really all there. The blue that constitutes the center triangle in the left panel looks darker, or more blue, than the surrounding blue. But it is not. Nor is the white central triangle in the right panel any brighter, or whiter, than the surrounding white. Both central triangles are optical illusions. They involve the perception of visual information not physically present in the visual sensory stimulus.

So, sometimes we perceive what is not there. Other times, we do not perceive what is there. And at still other times, we perceive what cannot be there.

The existence of perceptual illusions suggests that what we sense (in our sensory organs) is not necessarily what we perceive (in our minds). Our minds must take the available sensory information and manipulate that information to create mental representations of objects, properties, and spatial relationships within our environments (Peterson, 1999). The way we represent these objects will depend in part on our viewpoint in perceiving the objects (Edelman & Weinshall, 1991; Poggio & Edelman, 1990; Tarr, 1995; Tarr & Bülthoff, 1998).



■ **Figure 3.4** **Elusive Triangles: Real or Illusions?** You easily can see the triangles in this figure—or are the triangles just an illusion?

Source: Adapted from *In Search of the Human Mind* by Robert J. Sternberg, by Harcourt Brace & Company.

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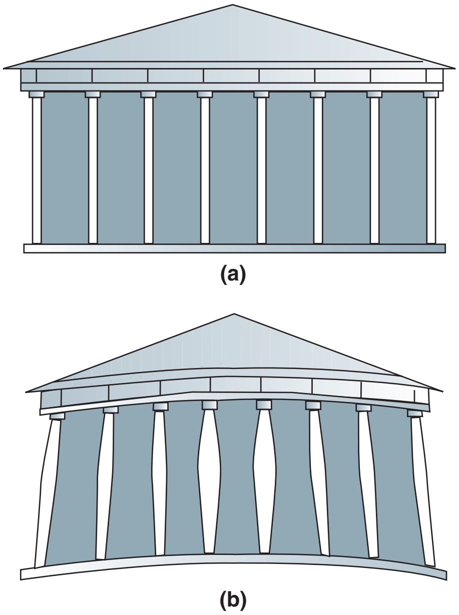

■ **Figure 3.5 The Parthenon.** The columns of the Parthenon in Greece actually bulge slightly in the middle (b) to compensate for the visual tendency to perceive that straight parallel lines (a) seem to curve inward. Similarly, the horizontal lines of the beams crossing the top of the columns and the top step of the porch bulge slightly upward to counteract the tendency to perceive that they curve slightly downward. In addition, the columns lean ever so slightly inward at the top to compensate for the tendency to perceive them as spreading out as we gaze upward at them. Architects consider these distortions of visual perception in their designs today.

An example in architecture is the use of optical illusions in the construction of the Parthenon (Figure 3.5 ■). Were the Parthenon actually constructed the way it appears to us perceptually (with strictly rectilinear form), its appearance would be bizarre.

Architects are not the only ones to recognize some fundamental principles of perception. For centuries, artists have known how to lead us to perceive 3-D percepts when viewing two-dimensional (2-D) images. What are some of the principles that guide our perceptions of both real and illusory percepts? We will explore the answer to this question as we move through the chapter. We begin with examining our visual system.

How Does Our Visual System Work?

The precondition for vision is the existence of light. Light is electromagnetic radiation that can be described in terms of wavelength. Humans can perceive only a small range of the wavelengths that exist; the visible wavelengths are from 380 to 750 nanometers (Figure 3.6 ■; Starr, Evers, & Starr, 2007).

Vision begins when light passes through the protective covering of the eye (Figure 3.7 ■). This covering, the *cornea,* is a clear dome that protects the eye. The light then passes through the *pupil,* the opening in the center of the *iris.* It continues through the *crystalline lens* and the *vitreous humor.* The vitreous humor is a gel-like substance that makes up the majority of the eye.

Eventually, the light focuses on the **retina** where electromagnetic light energy is transduced—that is, converted—into neural electrochemical impulses (Blake, 2000). Vision is most acute in the **fovea**, which is a small, thin region of the retina, the size of the head of a pin. When you look straight at an object, your eyes rotate so that the image

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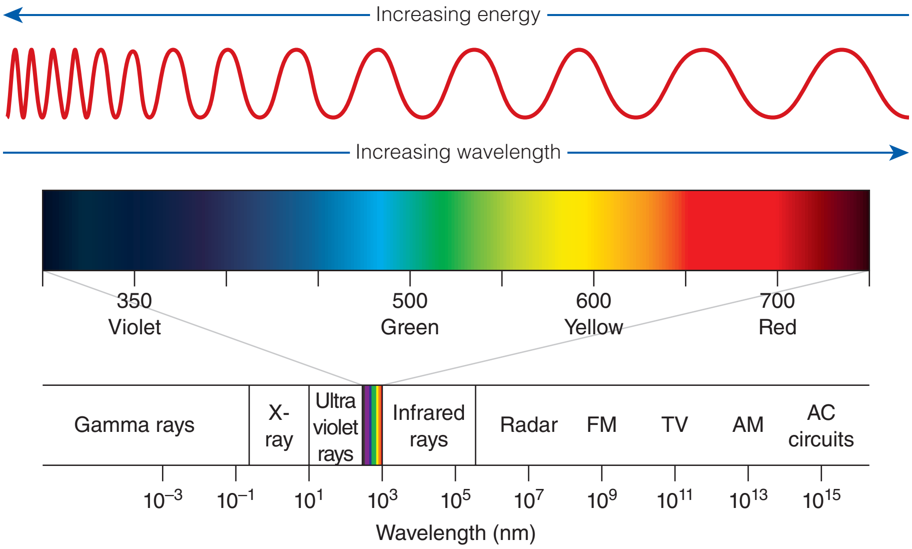
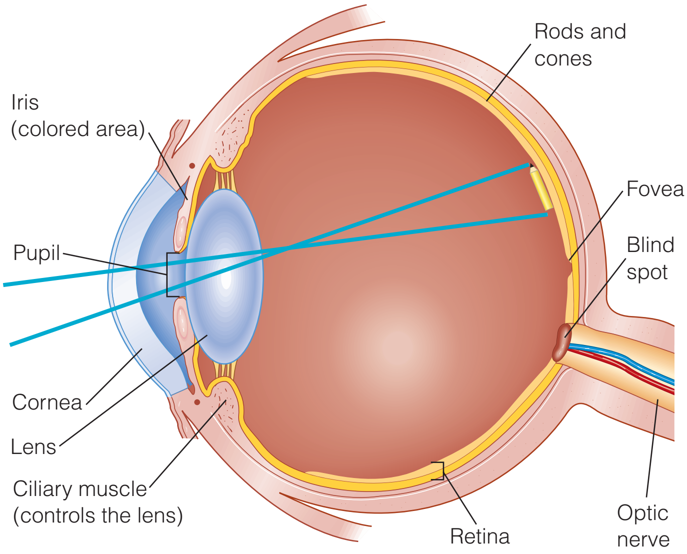


■ **Figure 3.6 The Electromagnetic Spectrum.** This image shows the different wavelengths that light comes in, and the small array of wavelengths that is actually visible to humans.

Source: Based on Kalat, *Biological Psychology,* 11e Figure 6.8.

falls directly onto the fovea. The retina contains the **photoreceptors**, which convert light energy into electrochemical energy that is transmitted by neurons to the brain. There are two kinds of photoreceptors—rods and cones. Each eye contains roughly 120 million rods and 8 million cones. Rods and cones differ not only in shape but also in their compositions, locations, and responses to light. Within the rods and cones are **photo pigments**, chemical substances that react to light and transform physical electromagnetic energy into an electrochemical neural impulse that can be understood by the brain. The **rods** are long and thin photoreceptors. They are more highly concentrated in the periphery of the retina than in the foveal region. The rods are responsible for night vision and



■ **Figure 3.7 The Human Eye.** The composition of the human eye.

are sensitive to light and dark stimuli. The **cones** are short and thick photoreceptors and allow for the perception of color. They are more highly concentrated in the foveal region than in the periphery of the retina (Durgin, 2000).

The rods and cones are connected to the brain. The neurochemical messages processed by the rods and cones of the retina travel via the **bipolar cells** to the **ganglion cells** (see Goodale, 2000a, 2000b). The axons of the ganglion cells in the eye collectively form the **optic nerve** for that eye. The optic nerves of the two eyes join at the base of the brain to form the *optic chiasma* (see Figure 2.8 in Chapter 2). At this point, the ganglion cells from the inward, or nasal, part of the retina—the part closer to your nose—cross through the optic chiasma and extend to the opposite hemisphere of the brain. The ganglion cells from the outward, or temporal area of the retina closer to your temple go to the hemisphere on the same side of the body. The lens of each eye naturally inverts the image of the world as it projects the image onto the retina. In this way, the message sent to your brain is literally upside-down and backward.

After being routed via the optic chiasma, about 90% of the ganglion cells then go to the lateral geniculate nucleus of the *thalamus*. From the thalamus, neurons carry information to the primary visual cortex (V1 or striate cortex) in the occipital lobe of the brain. The *visual cortex* contains several processing areas. Each area handles different kinds of visual information relating to intensity and quality, including color, location, depth, pattern, and form.

Pathways to Perceive the What and the Where

What are the visual pathways in the brain? A pathway in general is the path the visual information takes from its entering the human perceptual system through the eyes to its being completely processed. Generally, researchers agree that there are two pathways. Work on visual perception has identified separate neural pathways in the cerebral cortex for processing different aspects of the same stimuli (De Haan & Cowey, 2011; De Yoe & Van Essen, 1988; Köhler et al., 1995). Perception deficits, such as ataxia and agnosia, indicate the existence of different pathways. Both of these perception deficits are covered later in this chapter.

Why are there two pathways? The information from the primary visual cortex in the occipital lobe is forwarded through two fasciculi (fiber bundles): One ascends toward the parietal lobe (along the dorsal pathway), and one descends to the temporal lobe (along the ventral pathway). The dorsal pathway is also called the *where pathway* and is responsible for processing location and motion information; the ventral pathway is called the *what pathway* because it is mainly responsible for processing the color, shape, and identity of visual stimuli (Patel, Lin, & Khaderi, 2014; Ungerleider & Haxby, 1994; Ungerleider & Mishkin, 1982).

This is the *what–where hypothesis.* Most of the research in this area has been carried out with monkeys. In particular, a group of monkeys with lesions in the temporal lobe were able to indicate *where* things were but seemed unable to recognize *what* they were. In contrast, monkeys with lesions in the parietal lobe were able to recognize *what* things were but not *where* they were.

The *what–how hypothesis* is an alternative interpretation of the visual pathways (Goodale, 2011; Goodale & Milner, 2004; Goodale & Westwood, 2004). This hypothesis suggests the two pathways refer not to what things are and to where they are, but rather to what they are and to how they function. According to the *what–how hypothesis,* spatial information about where something is located in space is always present in visual information processing. What differs between the two pathways is whether the emphasis is on identifying what an object is or, instead, on how we can situate ourselves so as to grasp the object.

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The *what pathway* can be found in the ventral stream and is responsible for the identification of objects. The *how pathway* is located in the dorsal stream and controls movements in relation to the objects that have been identified through the *what* pathway. Ventral and dorsal streams both arise from the same early visual areas (Milner & Goodale, 2008).

The what–how hypothesis is best supported by evidence of processing deficits: There are deficits that impair people's ability to recognize *what* they see and there are distinct deficits that impair people's ability to reach for what they see (*how*).

CONCEPT CHECK

1. What is the difference between sensation and perception?
2. What is the difference between the distal and the perceptual object?
3. How are rods and cones both similar to and different from each other?
4. What are some of the major parts of the eye and what are their functions?
5. What is the *what–where* hypothesis?

Approaches to Perception: How Do We Make Sense of What We See?

Now that we know how a light stimulus that enters our eye is processed and routed to the brain, the question still remains as to *how* we actually perceive what we see. Do we just perceive whatever is being projected on our retina, or is there more to perception? Does our knowledge, and other rules we have learned throughout our life, perhaps influence our perception of the world? Going back to our view out of the window, the image on our retina suggests that the buildings we see in the distance are small. We do see other buildings, trees, and streets in front of them, however, that suggest that those buildings are in fact large and just appear small because they are far away from our office. In this case, our experience with and knowledge about perception and the world allow us to perceive those buildings as being tall even though they do not look larger than our hand in front of us on our desk.

There are different views on how we perceive the world. These views can be summarized as bottom-up theories and top-down theories. **Bottom-up theories** describe approaches in which perception starts with the stimuli whose appearance you take in through your eye. You look out onto the cityscape, and perception happens when the light information is transported to your brain. Therefore, they are data-driven (i.e., stimulus-driven) theories.

Not all theorists focus on the sensory data of the perceptual stimulus. Many theorists prefer **top-down theories**, according to which perception is driven by high-level cognitive processes, existing knowledge, and the prior expectations that influence perception (Clark, 2003). These theories then work their way down to considering the sensory data, such as the perceptual stimulus. You perceive buildings as big in the background of the city scene because you know these buildings are far away and therefore must be bigger than they appear. From this viewpoint, expectations are important. When people expect to see something, they may see it even if it is not there or is no longer there. For example, suppose people expect to see a certain person in a certain location. They may think they

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see that person, even if they are actually seeing someone else who looks only vaguely similar (Simons, 1996).

Top-down and bottom-up approaches have been applied to virtually every aspect of cognition. Bottom-up and top-down approaches usually are presented as being in opposition to each other. But to some extent, they deal with different aspects of the same phenomenon. Ultimately, a complete theory of perception will need to encompass both bottom-up and top-down processes.

Bottom-Up Theories

The four main bottom-up theories of form and pattern perception are direct perception, template theories, feature theories, and recognition-by-components theory.

Direct Perception

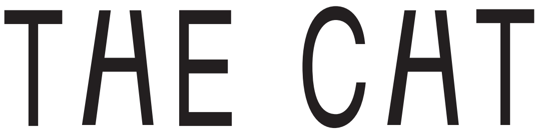
How do you know the letter *A* when you see it? Easy to ask, hard to answer. Of course, it's an *A* because it looks like an *A*. However, what makes it look like an *A* instead of like an *H?* Just how difficult it is to answer this question becomes apparent when you look at Figure 3.8 ■. You probably will see the image in Figure 3.8 as the words *THE CAT*. Yet the *H* of THE is identical to the *A* of CAT. What subjectively feels like a simple process of pattern recognition is almost certainly complex.

Gibson's Theory of Direct Perception How do we connect what we perceive to what we have stored in our minds?

According to Gibson's theory of **direct perception**, the information in our sensory receptors, including the sensory context, is all we need to perceive anything. As the environment supplies us with all the information we need for perception, this view is sometimes also called *ecological perception*. In other words, we do not need higher cognitive processes or anything else to mediate between our sensory experiences and our perceptions. Existing beliefs or higher-level inferential thought processes are not necessary for perception.

Gibson (1979) believed that, in the real world, sufficient contextual information usually exists to make perceptual judgments. We do not need to appeal to higher-level intelligent processes to explain perception but rather use contextual information directly. In essence, we are biologically tuned to respond to it. According to Gibson, we use texture gradients as cues for depth and distance. Those cues aid us to perceive directly the relative proximity or distance of objects and of parts of objects.

In Figure 3.9 ■, you can see different rock formations at the seacoast. For the rocks that are closest to the photographer, you can see many details, such as notches, holes, and variations in color. The farther away the objects on the picture are, the fewer the details you can see. You are using texture gradients as an indicator of how far away the rocks are. And because some of the rocks cover up parts of other rocks, you infer from that information that the rocks that are partly covered must be farther away than the rocks that cover them. On the basis of our analysis of the stable relationships among



■ Figure 3.8 **Can You Read These Words?** When you read these words, you probably have no difficulty differentiating the A from the *H*. Look more closely at each of these two letters. What features differentiate them?

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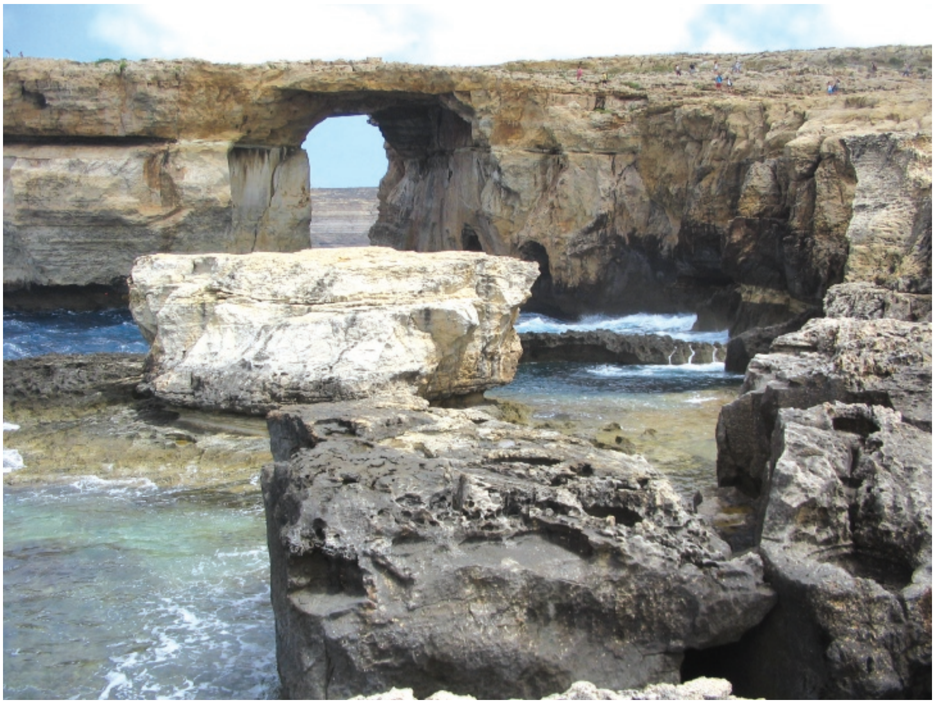

Courtesy of the author

Figure 3.9 **Cues Used in Depth Perception.** The farther away an object is, the fewer details you can see. You can see small holes and the rough texture of the rock in the foreground, whereas the rocks in the background look much smoother. The rock that is partly obscured is located behind the rock that obscures it. We use these cues to aid us in depth perception.

features of objects and settings in the real world, we directly perceive our environment (Gibson, 1950, 1954/1994; Mace, 1986). We do not need the aid of complex thought processes.

Such contextual information might not be readily controlled in a laboratory experiment. But such information is likely to be available in a real-world setting. Therefore, as noted previously, Gibson's model sometimes is referred to as an ecological model (Turvey, 2003). This reference is a result of Gibson's concern with perception as it occurs in the everyday world (the ecological environment) rather than in laboratory situations, where less contextual information is available.

Ecological constraints apply not only to initial perceptions but also to the ultimate internal representations (such as concepts) that are formed from those perceptions (de Wit, van der Kamp, & Withagen, 2015; Hubbard, 1995; Shepard, 1984). Continuing to wave the Gibsonian banner was Eleanor Gibson (1991, 1992), James's wife, and, like her husband, a highly distinguished scholar. She conducted landmark research in infant perception. She observed that infants (who certainly lack much prior knowledge and experience) quickly develop many aspects of perceptual awareness, including depth perception.

Direct perception may also play a role in interpersonal situations when we try to make sense of others' emotions and intentions (Gallagher, 2008). After all, we can almost instantaneously recognize facial expression as a whole emotion; we do not see multiple aspects of facial expressions that we then try, aspect by aspect, to piece together into the perception of an emotion (Wittgenstein, 1980).

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Neuroscience and Direct Perception Neuroscience also indicates that direct perception may be involved in person perception. About 30 to 100 milliseconds after a visual stimulus, mirror neurons start firing. Mirror neurons are active both when a person acts and when he or she observes that same act performed by somebody else. So before we even have time to form hypotheses about what we are perceiving, we may already be able to understand the expressions, emotions, and movements of the person we observe (Gallagher, 2008).

Furthermore, studies indicate that separate neural pathways (*what pathways*) in the lateral occipital area process form, color, and texture in objects. When asked to judge the length of an object, for example, people cannot ignore the width. Color, form, and texture of an object, however, can be judged independently of the other qualities (Cant & Goodale, 2007; Cant et al., 2008).

Template Theories

Template theories suggest that our minds store myriad sets of templates. **Templates** are highly detailed models for patterns we might recognize. We recognize a pattern by comparing it with our set of templates. We then choose the exact template that perfectly matches what we observe (Selfridge & Neisser, 1960). We see examples of template matching in our everyday lives. Fingerprints are matched in this way. Machines rapidly process imprinted numerals on checks by comparing them to templates. Products of all kinds are identified with universal product codes (UPCs or "bar codes"). They can be scanned and identified by computers at the time of purchase. Chess players who have knowledge of many games use a matching strategy in line with template theory to recall previous games (Gobet & Jackson, 2002). Template matching theories belong to the group of chunk-based theories; these theories suggest that expertise is attained by acquiring chunks of knowledge in long-term memory that can later be accessed for fast recognition. Studies with chess players have shown that the temporal lobe is indeed activated when the players access the stored chunks in their long-term memory (Campitelli et al., 2007).

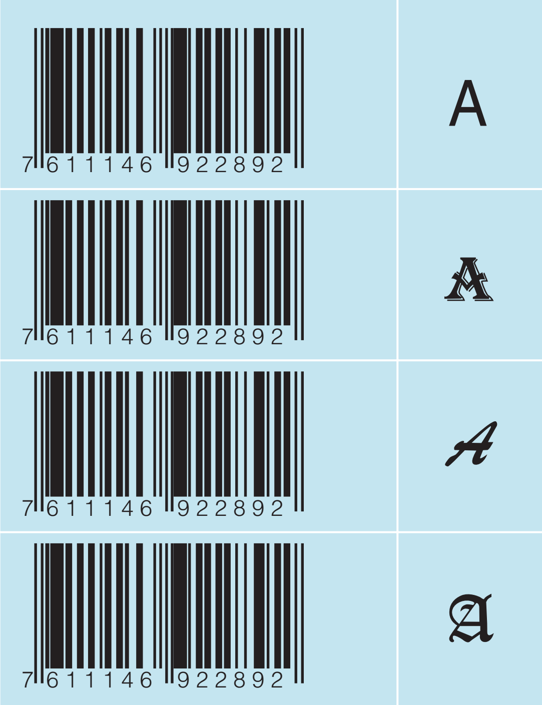
In each of these instances, the goal is to find one perfect match and disregard imperfect matches. You would be alarmed to find that your bank's numeral-recognition system failed to register a deposit to your account. Such failure might occur because it was programmed to accept an ambiguous character according to what seemed to be a best guess. For template matching, only an exact match will do. This is exactly what you want from a bank computer. Consider, however, your perceptual system at work in everyday situations. It rarely would work if you required exact matches for every stimulus you were to recognize. Imagine, for example, needing mental templates for every possible percept of the face of someone you love. Imagine one for each facial expression, each angle of viewing, each addition or removal of makeup, each hairdo, and so on.

Template-matching theories fail to explain some aspects of the perception of letters. For one thing, such theories cannot easily account for our perception of the letters and words in Figure 3.8 ("THE CAT"). We identify two different letters *(A* and *H*) from only one physical form. Hoffding (1891) noted other problems. We can recognize an *A* as an *A* despite variations in the size, orientation, and form in which the letter is written. Are we to believe that we have mental templates for each possible size, orientation, and form of a letter? Storing, organizing, and retrieving so many templates in memory would be unwieldy. How could we possibly anticipate and create so many templates for every conceivable object of perception (Figure 3.10 ■)?

Neuroscience and Template Theories Letters of the alphabet are simpler than faces and other complex stimuli. But how do we recognize letters? And does it make a difference to our brain whether we perceive letters or digits? Experiments suggest that there is indeed a difference between letters and digits. An area on or near the left fusiform gyrus (part of the occipital and temporal lobes) is activated significantly more when a person is presented with letters than with digits. It is not clear whether this "letter area" only processes letters or whether it also plays a more minor role in the processing of digits (Polk et al., 2002). The notion of the visual cortex specializing in different stimuli is not new; other areas have been found that specialize in faces, for example (see Kanwisher, McDermott, & Chun, 1997; McCarthy et al., 1997). Later in this chapter, we will consider in more detail the structures of the brain that enable us to recognize faces.

Why Computers Have Trouble Reading Handwriting

Think about how easy it is for you to perceive and understand someone's handwriting. In handwriting, everybody's numbers and letters look a bit different. You can still distinguish them without any problems (at least in most cases). This is something computers do not do well. For computers, reading handwriting is incredibly difficult and susceptible to mistakes. When you deposit a check at an automated teller machine, it "reads" your check automatically. In fact, the numbers at the bottom of your check that are written in a strange-looking font are so distinct that a machine cannot mistake them for one another. It is much harder, however, for a machine to decipher handwriting. Similarly, a machine also will have trouble determining that all the letters in the right of Figure 3.10 are *A*'s (unless it has a template for each one of the As). Therefore, some computers work with algorithms that consider the context in which the word is presented, the angular positions of the written letters (e.g., upright or tilted), and other factors.



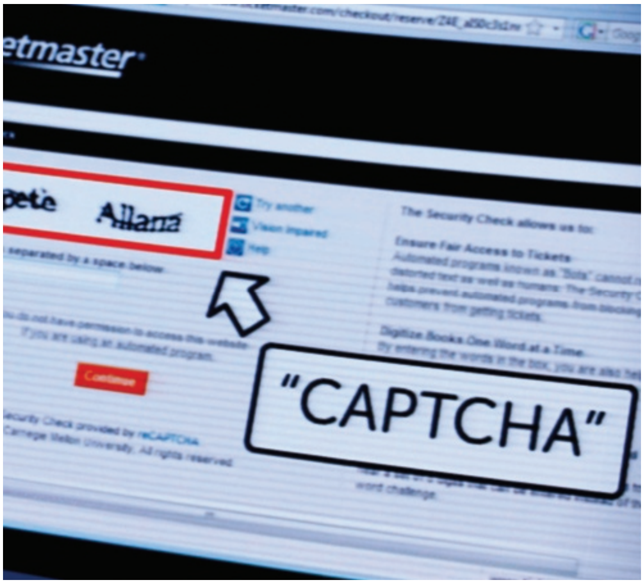
■ **Figure 3.10 Template Matching in Barcodes and Letters.** A particular barcode will always look exactly the same way, making it easy for computers to read. Letters, to the contrary, can look different although they depict the same letter. Template matching will distinguish between different bar codes but will not recognize that different versions of the letter *A* written in different scripts are indeed both *A*'s.

You are probably familiar with CAPTCHAs (Completely Automated Public Turing Test to Tell Computers and Humans Apart; see Figure 3.11) ■. They are used to tell humans and computers apart so that spamming machines cannot post spam on websites or sign up for e-mail accounts and send spam through those accounts. CAPTCHAs capitalize on the fact that most approaches to machine vision use template matching (Hannagan et al., 2012). But as you can imagine, new approaches are continuously being developed to improve reading abilities of machines so, at some point, CAPTCHAs might have to be developed that are more intricate.

Feature-Matching Theories

Yet another alternative explanation of pattern and form perception may be found in **feature-matching theories**. According to these theories, we attempt to match features of a pattern to features stored in memory, rather than to match a whole pattern to a template or a prototype (Stankiewicz, 2003).

The Pandemonium Model One such feature-matching model has been called *Pandemonium* ("pandemonium" refers to a noisy, chaotic place and hell). In this model, metaphorical "demons" with specific duties receive and analyze the features of a stimulus (Selfridge, 1959).



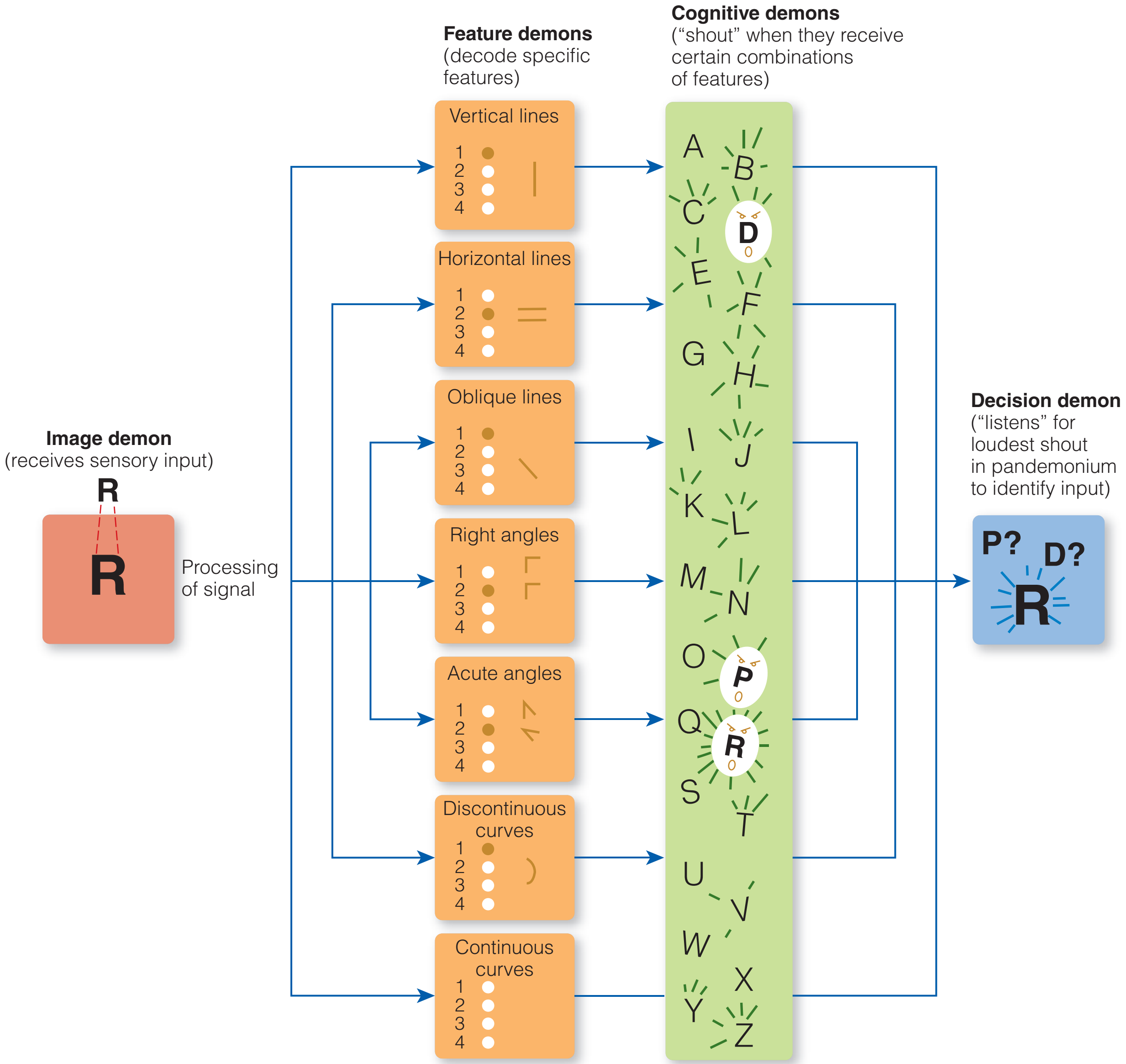
epa european pressphoto agency b.v./Alamy

■ **Figure 3.11** CAPTCHAS are used to tell humans and computers apart.

In the Pandemonium model, conceived by Oliver Selfridge, there are four kinds of demons: image demons, feature demons, cognitive demons, and decision demons. Figure 3.12 ■ shows this model. The "image demons" receive a retinal image and pass it on to "feature demons." Each feature demon calls out when matches are made between the stimulus and the given feature. These matches are yelled out at demons at the next level of the hierarchy, the "cognitive (thinking) demons." The cognitive demons in turn shout out possible patterns stored in memory that conform to one or more of the features noticed by the feature demons. A "decision demon" listens to the pandemonium of the cognitive demons. It decides on what has been seen, based on which cognitive demon is shouting the most frequently (i.e., which has the most matching features).

Other feature models have been proposed (Grainger, Rey, & Dufau, 2008), but Selfridge's Pandemonium model is one of the most widely known. Most other feature models distinguish different features as well as different kinds of features, such as global versus local features. Local features constitute the small-scale or detailed aspects of a given pattern. There is no consensus as to what exactly constitutes a local feature. Nevertheless, we generally can distinguish such features from global features, the features that give a form its overall shape. Consider, for example, the stimuli depicted in Figures 3.13(a) ■ and 3.13(b) ■. These are of the type used in some research on pattern perception (e.g., see Navon, 1977, or Olesen et al., 2007). Globally, the stimuli in panels (a) and (b) form the letter *H*. In panel (a), the local features (small *H*'s) correspond to the global ones. In panel (b), including many local letter *S*'s, they do not.

In one study, participants were asked to identify the stimuli at either the global or the local level (Navon, 1977). When the local letters were small and positioned close together, participants could identify stimuli at the global level (the "big" letter) more quickly than at the local level. When participants were required to identify stimuli at the global level, whether the local features (small letters) matched the global one (big letter) did not matter. They responded equally rapidly whether the global *H* was made up of local *H*'s or of local *S*'s. However, when the participants were asked to identify the "small" local letters, they responded more quickly if the global features agreed with the local ones. In other


Feature demons
(decode specific features)
Cognitive demons
("shout" when they receive certain combinations of features)
Image demon
(receives sensory input)
R
R
Processing of signal
Vertical lines
1 2 3 4
Horizontal lines
1 2 3 4
Oblique lines
1 2 3 4
Right angles
1 2 3 4
Acute angles
1 2 3 4
Discontinuous curves
1 2 3 4
Continuous curves
1 2 3 4
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
Decision demon
("listens" for loudest shout in pandemonium to identify input)
P?
D?
R

■ **Figure 3.12** **Selfridge's Feature-Matching Model.** According to Oliver Selfridge's feature-matching model, we recognize patterns by matching observed features to features already stored in memory. We recognize the patterns for which we have found the greatest number of matches. In the example above, the feature demons indicate that the sensory input (the letter *R*) has one vertical line, two horizontal lines, one oblique line, two right angles, two acute angles, and one discontinuous curve. These features permit the cognitive demons to conclude that the letter in question may be either the letter D, P, or R. The decision demon then makes a decision on which letter has been perceived.

words, they were slowed down if they had to identify local (small) *S*'s combining to form a global (big) *H* instead of identifying local (small) *H*'s combining to form a global (big) *H*. This pattern of results is called the *global precedence effect* (see also Kimchi, 1992). Experiments show global information dominates over local information even in infants (Cassia et al., 2002).

In contrast, when letters are more widely spaced, as in Figures 3.14(a) ■ and 3.14(b) ■, the effect is reversed. Then a *local precedence* effect appears. That is, the

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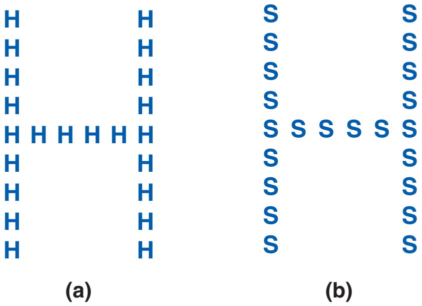

Figure 3.13 The Global Precedence Effect. Compare panel (a), a global *H* made of local *H*'s, with panel (b), a global *H* made of local *S*'s. All the local letters are tightly spaced.

Source: Based on D. Navon, "Forest before Trees: The Precedence to Global Features in Visual Perception," *Cognitive Psychology*, July 1977, Vol. 9, No. 3, pp. 353–382.

participants more quickly identify the local features of the individual letters than the global ones, and the local features interfere with the global recognition in cases of contradictory stimuli (Martin, 1979). So when the letters are close together at the local level, people have problems identifying the local stimuli (small letters) if they are not concordant with the global stimulus (big letter). When the letters on the local level are relatively far apart from each other, it is harder for people to identify the global stimulus (big letter) if it is not concordant with the local stimuli (small letters). Other limitations (e.g., the size of the stimuli) besides special proximity of the local stimuli hold as well, and other kinds of features also influence perception.

Neuroscience and Feature-Matching Theories Some support for feature theories comes from neurological and physiological research. Researchers used single-cell recording techniques with animals (Hubel & Wiesel, 1963, 1968, 1979). They carefully measured the responses of individual neurons to visual stimuli in the visual cortex. Then they mapped those neurons to corresponding visual stimuli for particular locations in the visual field (see Chapter 2). Their research showed that the visual cortex contains specific neurons that respond only to a particular kind of stimulus (e.g., a horizontal line), and only if that stimulus fell onto a specific region of the retina. Each individual cortical neuron, therefore, can be mapped to a specific receptive field on the retina. A disproportionately large amount of the visual cortex is devoted to neurons mapped to receptive fields in the foveal region of the retina, which is the area of the most acute vision.

Most of the cells in the cortex do not respond simply to spots of light. Rather, they respond to "specifically oriented line segments" (Hubel & Wiesel, 1979, p. 9). Moreover, these cells seem to show a hierarchical structure in the degree of complexity of the stimuli to which they respond, somewhat in line with the ideas behind the Pandemonium Model. That means that the outputs of the cells are combined to create higher-order detectors that can identify increasingly more complex features. At the lowest level, cells respond to lines; at a higher level, they respond to corners and edges, then to shapes, and so forth. Neurons that can recognize a complex object are called *gnostic units* or "grandmother cells" because they imply that there is a neuron that is capable of recognizing your grandmother. None of those neurons are so specific, however, that they respond to just one person's head. Even at such a high level,

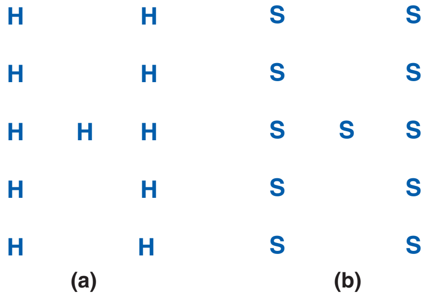

Figure 3.14 The Local Precedence Effect. Compare panels (a) and (b), in which the local letters are widely spaced. Why does Figure 3.13 show the global precedence effect, and why does Figure 3.14 show the local precedence effect?

Source: Based on D. Navon, "Forest before Trees: The Precedence to Global Features in Visual Perception," *Cognitive Psychology*, July 1977, Vol. 9, No. 3, pp. 353–382.

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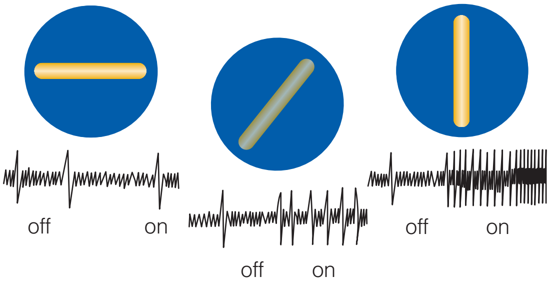


■ **Figure 3.15 Line Orientation and Cell Activation.** David Hubel and Torsten Wiesel discovered that cells in our visual cortex become activated only when they detect the sensation of line segments of particular orientations. As you can see, there is hardly any activation when the cell is presented with a horizontal line segment. There is more activation when the line is diagonally oriented, and when the line is vertical, the cell reacts with even more activation.

Source: Based on *In Search of the Human Mind* by Robert J. Sternberg, copyright © 1995 by Harcourt Brace & Company.

some selectivity involved still allows cells to generally fire when a human face comes into view.

Consider what happens as the stimulus proceeds through the visual system to higher levels in the cortex. In general, the size of the receptive field increases, as does the complexity of the stimulus required to prompt a response. As evidence of this hierarchy, there were once believed to be just two kinds of visual cortex neurons (Figure 3.15 ■), *simple cells* and *complex cells* (Hubel & Wiesel, 1979), which were believed to differ in the complexity of the information about stimuli they processed. This view proved to be oversimplified.

On the basis of Hubel and Wiesel's work, other investigators have found feature detectors that respond to corners, angles, stars, or triangles (DeValois & DeValois, 1980; Shapley & Lennie, 1985; Tanaka, 1993). In some areas of the cortex, highly sophisticated complex cells fire maximally only in response to specific shapes, regardless of the size of the given stimulus. Examples would be a hand or a face. As the stimulus decreasingly resembles the optimal shape, these cells are decreasingly likely to fire.

We now know the picture is more complex than Hubel and Wiesel imagined. Cells can serve multiple functions. These cells operate partially in parallel, although we are not conscious of their operation. For example, spatial information about locations of perceived objects was found to be processed simultaneously with information about the contours of the object. Complex judgments about what is perceived are made fairly early in information processing and in parallel (Dakin & Hess, 1999).

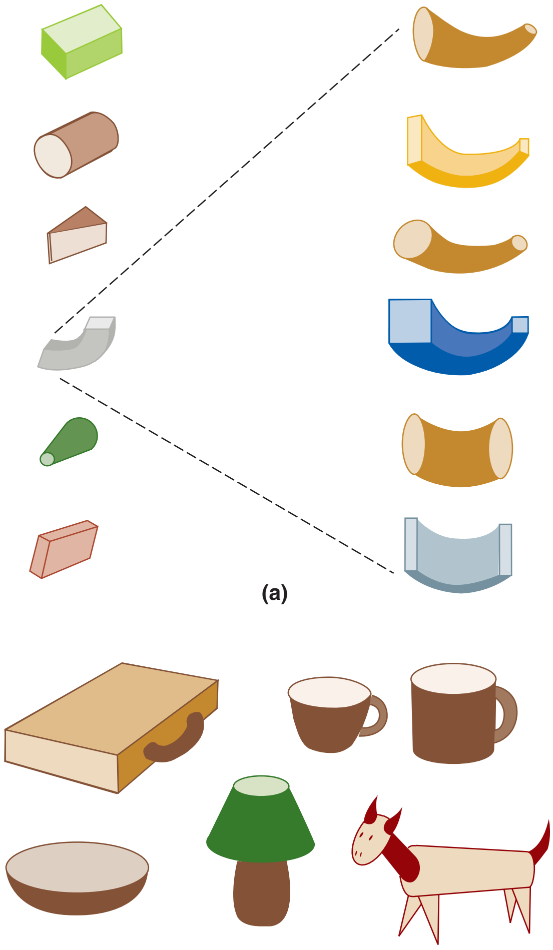
But once discrete features have been analyzed according to their orientations, how are they integrated into a form we can recognize as particular objects? The recognition-by-components theory we will consider next sheds some light on this question.

Recognition-by-Components Theory

How do we form stable 3-D mental representations of objects? The recognition-by-components theory explains it, using simple geometric shapes.

Seeing with the Help of Geons Irving Biederman (1987) suggested that we recognize 3-D objects by manipulating simple geometric shapes called geons (for geometrical ions). These shapes include objects such as bricks, cylinders, wedges, cones, and their curved axis counterparts (Biederman, 1990/1993b). According to Biederman's **recognition-by-components (RBC) theory**, we quickly recognize objects by observing the edges of them and then decomposing the objects into geons. The geons also can be recomposed into alternative arrangements. You know that a small set of letters can be manipulated to compose countless words and sentences. Similarly, a small number of geons can be used to build up many basic shapes and then myriad basic objects (Figure 3.16 ■).

The geons are simple and function regardless of viewpoint—they are viewpoint-invariant. The objects constructed from geons thus are recognized easily from many perspectives, despite visual noise. According to Biederman (1993a, 2001), his RBC theory parsimoniously explains how we recognize the general classification for multitudinous objects quickly, automatically, and accurately. This recognition occurs despite changes in viewpoint. It occurs even when the stimulus object is degraded in some way. For example, if you see a car, you perceive it as being made up of a number of different geons. You can recognize the car even if it is partly obscured by another object and you can't see



■ **Figure 3.16 Geons.** Irving Biederman amplified feature-matching theory by proposing a set of elementary components of patterns (a), which he based on variations in 3-D shapes derived in large part from a cone (b).

all of the geons. This is because you can still infer the presence of the other geons. Cells in the inferior temporal cortex (i.e., the lower part of the temporal cortex) react stronger to changes in geons than to changes in other geometrical properties (e.g., changes in the size or diameter of a cylinder; Vogels et al., 2001). The viewpoint invariance also can be seen in faces: Both children and adults can recognize faces from different viewpoints (although recognition is somewhat worse for a face that is presented from a viewpoint different from the one in which the face was first presented). In fact, one study showed that there was no significant difference between the face-recognition performance of adults and 8-year old children, suggesting that the ability to recognize faces from different viewpoints develops early on (Crookes & Robbins, 2014).

Biederman's RBC theory explains how we may recognize general instances of chairs, lamps, and faces, but it does not adequately explain how we recognize particular chairs or particular faces. An example would be your own face or your best friend's face. They are both made up of geons that constitute your mouth, eyes, nose, eyebrows, and so forth. But these geons are the same for both your and your friend's faces. So RBC theory cannot explain how we can distinguish one face from the next.

Biederman recognized that aspects of his theory require further work, such as how the relations among the parts of an object can be described (Biederman, 1990/1993b). Another problem with Biederman's approach, and the bottom-up approach in general, is how to account for the effects of prior expectations and environmental context on some phenomena of pattern perception.

Neuroscience and Recognition-by-Components Theory What results would we expect if we were to confirm Biederman's theory? Geons are viewpoint-invariant, so studies should show that neurons exist that react to properties of an object that stay the same, no matter whether you look at them from the front or the side. And indeed, studies have found neurons in the inferior temporal cortex that are sensitive to just those viewpoint-invariant properties (Vogels et al., 2001). Many neurons, however, respond primarily to one view of an object and decrease their response gradually the more the object is rotated (Logothetis, Pauls, & Poggio, 1995). This finding contradicts the notion of Biederman's theory that we recognize objects by means of viewpoint-invariant geons. As a result, it is not clear at this point whether Biederman's theory is correct.

Top-Down Theories

In contrast to the bottom-up approach to perception is the top-down, constructive approach (Bruner, 1957; Gregory, 1980; Rock, 1983; von Helmholtz, 1909/1962; Wolfe, Kluender, & Levi, 2011). In **constructive perception**, the perceiver builds (constructs) a cognitive understanding (perception) of a stimulus. The concepts of the perceiver and his or her cognitive processes influence what he or she sees. The perceiver uses sensory information as the foundation for the structure but also uses other sources of information to build the perception. This viewpoint also is known as *intelligent perception* because it states that higher-order thinking plays an important role in perception. It also emphasizes the role of learning in perception (Fahle, 2003). Some investigators have pointed out that not only does the world affect our perception but also the world we experience is actually formed by our perception (Goldstone, 2003). In other words, perception is reciprocal with the world we experience. Perception both affects and is affected by the world as we experience it.

An interesting feature of the theory of constructive perception is that it links human intelligence even to fairly basic processes of perception. According to this theory, perception includes not merely a low-level set of cognitive processes but actually a sophisticated set of processes that interact with and are guided by human intelligence. When you look out your window, you "see" many things, but what you recognize yourself as seeing is highly processed by your intelligence. Interestingly, Titchener's structuralist approach (described in Chapter 1) ultimately failed because despite the efforts of Titchener and his followers to engage in introspection independently of their prior knowledge, they and others found this, in the end, to be impossible. What you perceive is shaped, at some level, by what you know and what you think.

For example, picture yourself driving down a road you have never traveled before. As you approach a blind intersection, you see an octagonal red sign with white lettering. It bears the letters *ST_P*. An overgrown vine cuts between the *T* and the *P*. Chances are, you will construct from your sensations a perception of a stop sign. You thus will respond appropriately. Perceptual constancies are another example (see "Perceptual Constancies," p. 104). When you see a car approaching you on the street, its image on your retina gets bigger as the car comes closer. And yet, you perceive the car to stay the same size. This suggests that high-level constructive processes are at work during perception. In color constancy, we perceive that the color of an object remains the same despite changes in lighting that alter the hue. Even in lighting that becomes so dim that color sensations are virtually absent, we still perceive bananas as yellow, plums as purple, and so on.

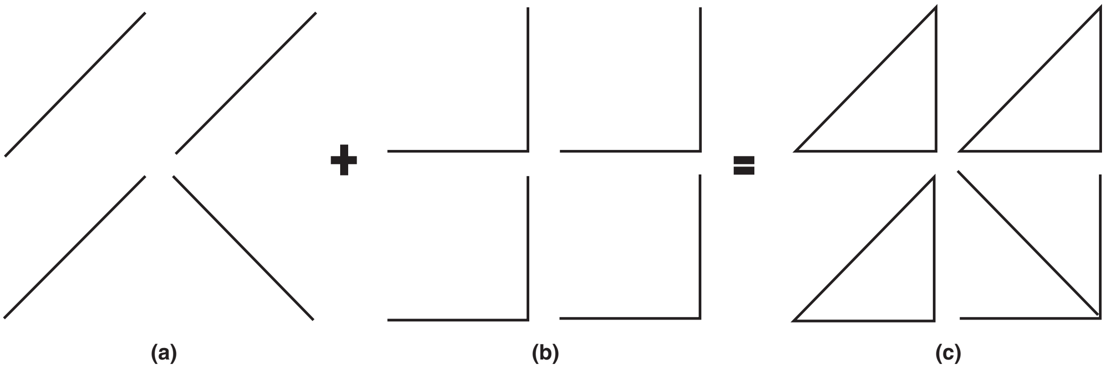
According to constructivists, during perception, we quickly form and test various hypotheses regarding percepts. The percepts are based on the following:

- what we sense (the sensory data)
- what we know (knowledge stored in memory)
- what we can infer (using high-level cognitive processes)

In perception, we consider prior expectations. You'll be fast to recognize your friend from far away on the street when you have arranged a meeting. We also use what we know about the context. When you see something approaching on rail tracks, you infer that it must be a train. And we also may use what we reasonably can infer, based both on what the data are and on what we know about the data. According to constructivists, we usually make the correct attributions regarding our visual sensations. The reason is that we perform unconscious inference, the process by which we unconsciously assimilate information from a number of sources to create a perception (Snow & Mattingley, 2003). In other words, using more than one source of information, we make judgments that we are not even aware of making.

In the stop-sign example, sensory information implies that the sign is a meaningless assortment of oddly spaced consonants. However, your prior learning tells you something important—that a sign of this shape and color posted at an intersection of roadways and containing these three letters in this sequence probably means that you should stop thinking about the odd letters. Instead, you should start slamming on the brakes. Successful constructive perception requires intelligence and thought in combining sensory information with knowledge gained from previous experience.

One reason for favoring the constructive approach is that bottom-up (data-driven) theories of perception do not fully explain context effects. **Context effects** are the influences of the surrounding environment on perception (e.g., our perception of "THE CAT" in Figure 3.8). Fairly dramatic context effects can be demonstrated experimentally (Biederman, 1972; Biederman et al., 1974; Biederman, Glass, & Stacy, 1973; Davenport, 2007). In one study, people were asked to identify objects after they had viewed the objects in either an appropriate or an inappropriate context for the items (Palmer, 1975). For example, participants might see a scene of a kitchen followed by stimuli such as a loaf



■ **Figure 3.17** **The Configural-Superiority Effect.** Subjects more readily perceive differences among integrated configurations comprising multiple lines (c) than they do solitary lines (a). In this figure, the lines in panel (b) are added to the lines in panel (a) to form shapes in panel (c), thereby making panel (c) more complex than panel (a).

of bread, a mailbox, and a drum. Objects that were appropriate to the established context, such as the loaf of bread in this example, were recognized more rapidly than were objects that were inappropriate to the established context. The strength of the context also plays a role in object recognition (Bar, 2004).

Perhaps even more striking is a context effect known as the *configural-superiority effect* (Bar, 2004; Pomerantz, 1981, 2003), by which objects presented in certain configurations are easier to recognize than the objects presented in isolation, even if the objects in the configurations are more complex than those in isolation. Suppose you show a participant four stimuli, all of them diagonal lines [see Figure 3.17(a) ■]. Three of the lines are slanting one way, and one line is slanting the other way. The participant's task is to identify which stimulus is unlike the others. Now suppose that you show participants four stimuli that are composed of three lines each [Figure 3.17(c) ■]. Three of the stimuli are shaped like triangles, and one is not. In each case, the stimulus is a diagonal line [Figure 3.17(a)] plus other lines [Figure 3.17(b) ■]. Thus, the stimuli in this second condition are more complex variations of the stimuli in the first condition. Participants, however, can more quickly spot which of the three-sided, more complicated figures is different from the others than they can spot which of the lines is different from the others.

Similarly, there is an *object-superiority effect*, in which a target line that forms a part of a drawing of a 3-D object is identified more accurately than a target that forms a part of a disconnected 2-D pattern (Lanze, Weisstein, & Harris, 1982; Weisstein & Harris, 1974). These findings parallel findings in the study of letter and word recognition: The *word-superiority effect* indicates that when people are presented with strings of letters, it is easier for them to identify a single letter if the string makes sense and forms a word instead of being just a nonsense sequel of letters. For example, it is easier to recognize the letter *o* in the word *house* than in the word *huseo* (Reicher, 1969).

The viewpoint of constructive or intelligent perception shows the central relation between perception and intelligence. According to this viewpoint, intelligence is an integral part of our perceptual processing. We do not perceive simply in terms of what is "out there in the world." Rather, we perceive in terms of the expectations and other cognitions we bring to our interaction with the world. In this view, intelligence and perceptual processes interact in the formation of our beliefs about what it is that we are encountering in our everyday contacts with the world at large.

An extreme top-down position would drastically underestimate the importance of sensory data. If it were correct, we would be susceptible to gross inaccuracies of perception. We frequently would form hypotheses and expectancies that inadequately evaluated the sensory data available. For example, if we expected to see a friend and someone else came into view, we might inadequately consider the perceptible differences between the friend and a stranger and mistake the stranger for the friend. Thus, an extreme constructivist view of perception would be highly error-prone and inefficient. An extreme bottom-up position, however, would not allow for any influence of past experience or knowledge on perception. Why store knowledge that has no use for the perceiver? Neither extreme is ideal for explaining perception. It is more fruitful to consider ways in which bottom-up and top-down processes interact to form meaningful percepts.

How Do Bottom-Up Theories and Top-Down Theories Go Together?

Both theoretical approaches have garnered empirical support (Cutting & Kozlowski, 1977, cf. Palmer, 1975). So how do we decide between the two? On one level, the constructive-perception theory, which is more top-down, seems to contradict direct-perception theory, which is more bottom-up. Constructivists emphasize the importance of prior knowledge in combination with relatively simple and ambiguous information from the sensory receptors. In contrast, direct perception theorists emphasize the completeness of the information in the receptors themselves. They suggest that perception occurs simply and directly. Thus, there is little need for complex information processing.

Instead of viewing these theoretical approaches as incompatible, we may gain deeper insight into perception by considering the approaches to be complementary. Sensory information may be more richly informative and less ambiguous in interpreting experiences than the constructivists would suggest. But it may be less informative than the direct-perception theorists would assert. Similarly, perceptual processes may be more complex than hypothesized by Gibsonian theorists. This would be particularly true under conditions in which the sensory stimuli appear only briefly or are degraded. Degraded stimuli are less informative for various reasons. For example, the stimuli may be partially obscured or weakened by poor lighting. Or they may be incomplete, or distorted by illusory cues or other visual "noise" (distracting visual stimulation analogous to audible noise). We likely use a combination of information from the sensory receptors and our past knowledge to make sense of what we perceive. Some experimental evidence supports this integrated view (Treue, 2003; van Zoest & Donk, 2004; Wolfe et al., 2003).

Recent work suggests that whereas the first stage of the visual pathway represents only what is in the retinal image of an object, very soon, color, orientation, motion, depth, spatial frequency, and temporal frequency are represented. Later-stage representations emphasize the viewer's current interest or attention. In other words, the later-stage representations are not independent of our attentional focus. On the contrary, they are directly affected by it (Maunsell, 1995). Moreover, vision for different things can take different forms. Visual control of action is mediated by cortical pathways that are different from those involved in visual control of perception (Ganel & Goodale, 2003). In other words, when we merely see an object, such as a cell phone, we process it differently than if we intend also to pick up the object. In general, according to Ganel and Goodale (2003), we perceive objects holistically. But if we plan to act on them, we perceive them more analytically so that we can act in an effective way.

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To summarize, current theories concerning the ways we perceive patterns explain some, but not all, of the phenomena we encounter in the study of form and pattern perception. Given the complexity of the process, it is impressive that we understand as much as we do. At the same time, clearly a comprehensive theory is still forthcoming. Such a theory would need to account fully for the kinds of context effects, such as the configural-superiority effect, described in this section.

in the lab of **MARVIN CHUN**

What Happens to Unattended Information?

Marvin Chun

Marvin Chun

Apollo Robins, the gentleman thief, can pick your pockets clean without your noticing it, even after telling you that he will be stealing from you, or even if you are on security detail for the Secret Service. Magicians and illusionists are not just deft with their hands, but have the more magical ability to control your attention. Because perception is a construction of the mind, whoever can control your attention governs what you perceive. Most of what we see, hear, feel, smell, taste, and even remember depends on what we select and attend to. Unattended information slips by—gorillas go unnoticed, pockets get picked, or traffic signals missed by distracted observers focused elsewhere. What happens to the rivers of unattended information that pass by us all the time? My laboratory uses both behavioral methods and functional magnetic resonance imaging (fMRI) to study the fate of unattended, ignored events.

Consider a lab task of searching for two letters among digits presented sequentially at a blindingly fast rate of 10 items per second, MTV style. People have a fleeting sense of what's going by and can pick out the first letter around 90% of the time. However, if the second letter appears about 200–300 milliseconds after the first letter target, it is missed up to 70% of the time. This phenomenon, known as the attentional blink (Raymond et al., 1992), is a form of inattentional blindness that highlights fundamental limitations regarding how much you can attend.

But what happens to the missed target? We proposed that missed targets are identified but then get lost or forgotten while waiting for the first target to be encoded (Chun & Potter, 1995). However, it was difficult to prove unconscious identification with behavioral methods alone. Hence, we used fMRI to investigate subliminal processing during the attentional blink. fMRI can directly probe how information is processed in different brain areas, even when subjects cannot report them. A region of the brain called the *parahippocampal gyrus* is devoted to scene processing; this "place area" is more active when scenes are viewed.

Our experiment presented scenes as second targets to be missed during the attentional blink. First, we measured the fMRI signal in the place area to scenes that were presented and consciously detected by the subject (the experiment was designed so that about half would be detected probabilistically). We also measured the lower boundary of activity in the place area for trials when no scenes were presented.

The focus of the study was then to ask how the place area responds to scenes that were missed. When subjects said they could not see the scene, did the place area unconsciously see the scene? If so, the fMRI signal in the place area to unseen scenes should be higher than the lower-bound baseline when no scene was presented. Indeed, the place area produced significantly higher fMRI signals, suggesting that subliminal perception occurs to a high level (scene detection) and that fMRI can be used to measure such unconscious processing (Marois et al., 2004).

Attention modulates not just ongoing perception, but also your ability to remember (Chun & Johnson, 2011; Chun & Turk-Browne, 2007). Simply looking at or reading something does not ensure you will encode it, as you may know all too well while studying for exams. You must attend to the information you're trying to learn, or memory traces of the information will not be formed reliably in brain circuits important for memory. In fact, using fMRI we demonstrated that attention is important both during encoding and when trying to retrieve information (Kuhl, Bainbridge, & Chun 2012; Yi & Chun, 2005). Unfortunately, for students, learning without attention seems unlikely!

Perception of Objects and Forms

Do we perceive objects in a viewer-centered or in an object-centered way? When we gaze at any object in the space around us, do we perceive it in relation to us rather than its actual structure, or do we perceive it in a more objective way that is independent of how it appears to us right this moment? We'll examine this question in the next section. Then, we look at Gestalt principles for perception, which explain why we perceive some objects as in groups but others as not so grouped (what is it that makes some birds flying in the afternoon sky appear to be in a group, whereas others do not?). Finally, we will consider the question of how we perceive patterns, for example, faces.

Viewer-Centered versus Object-Centered Perception

Right now one of your authors is looking at the computer on which he is typing this text. He depicts the results of what he sees as a mental representation. What form does this mental representation take? There are two common positions regarding the answer to this question.

One position, **viewer-centered representation**, is that the individual stores the way the object looks to him or her. Thus, what matters is the appearance of the object to the viewer (in this case, the appearance of the computer to the author), not the actual structure of the object. The shape of the object changes, depending on the angle from which we look at it. A number of views of the object are stored, and when we try to recognize an object, we have to rotate that object in our mind until it fits one of the stored images.

The second position, **object-centered representation**, is that the individual stores a representation of the object, independent of its appearance to the viewer. In this case, the shape of the object will stay stable across different orientations (McMullen & Farah, 1991). This stability can be achieved by establishing the major and minor axes of the object, which then serve as a basis for defining further properties of the object.

Both positions can account for how the author represents a given object and its parts. The key difference is in whether he represents the object and its parts in relation to him (viewer-centered) or in relation to the entirety of the object itself, independent of his own position (object-centered).

Consider, for example, the computer on which this text is being written. It has different parts: a screen, a keyboard, a mouse, and so forth. Suppose the author represents the computer in terms of viewer-centered representation. Then its various parts are stored in terms of their relation to him. He sees the screen as facing him at perhaps a 20-degree angle. He sees the keyboard facing him horizontally. He sees the mouse off to the right side and in front of him. Suppose, instead, that he uses an object-centered representation. Then he would see the screen at a 70-degree angle relative to the keyboard. And the mouse is directly to the right side of the keyboard, neither in front of it nor in back of it.

Recent research suggests that it is more likely we engage in viewer-centered representation than object-centered representation (Hayward, 2012). Think about the many different variations that occur when an object is viewed from different perspectives. It would be an enormous, if not impossible, effort to compute invariant shape descriptions from this information. Neuroscience points in this direction as well. If neurons responded to object-centered representations, they would not much react to changes in view because different views of the same object would activate the same neural network. However, it has been found that neurons indeed do react to changes in view (Davies-Thompson, 2009).

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A third orientation in representation is **landmark-centered**. In landmark-centered representation, information is characterized by its relation to a well-known or prominent item. Imagine visiting a new city. Each day you leave your hotel and go on short trips. It is easy to imagine that you would represent the area you explore in relation to your hotel.

Evidence indicates that, in the laboratory, participants can switch among these three strategies. There are, however, differences in brain activation among these strategies (Committeri et al., 2004).

The Perception of Groups—Gestalt Laws

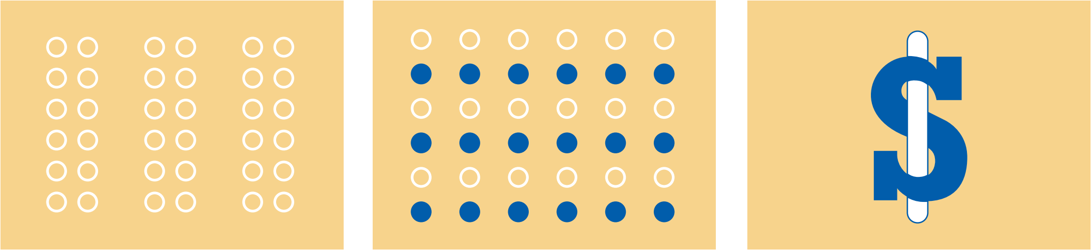
Perception helps us make sense of the confusing stimuli that we perceive in the world. One way to bring order and coherence into our perception is our ability to group similar things. This way, we can reduce the number of things that need to be processed. We can better decide which things belong together or to the same object. In other words, we organize objects in a visual array into coherent groups.

The **Gestalt approach to form perception** that was developed in Germany in the early twentieth century is particularly useful for understanding how we perceive groups of objects or even parts of objects to form integral wholes (Palmer, 1999a, 1999b, 2000; Palmer & Rock, 1994; Prinzmetal, 1995). The approach was founded by Kurt Koffka (1886–1941), Wolfgang Köhler (1887–1968), and Max Wertheimer (1880–1943) and was based on the notion that the whole differs from the sum of its individual parts (see Chapter 1).

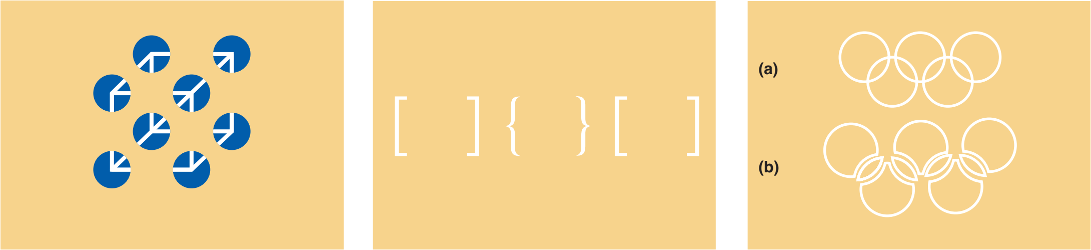
The overarching law of the Gestalt approach is the **law of Prägnanz**. We tend to perceive any given visual array in a way that most simply organizes the different elements into a stable and coherent form. Thus, we do not merely experience a jumble of unintelligible, disorganized sensations. For example, we tend to perceive a focal figure and other sensations as forming a background for the figure on which we focus.

Other Gestalt principles include *figure-ground perception*, *proximity*, *similarity*, *continuity*, *closure*, and *symmetry* (Figure 3.18 ■; see also Table 3.2 ■). Each of these principles supports the overarching law of Prägnanz. Each illustrates how we tend to perceive visual arrays in ways that most simply organize the disparate elements into a stable and coherent form. Stop for a moment and look at your environment. You will perceive a coherent, complete, and continuous array of figures and background. You do not perceive holes in objects where your textbook covers up your view of them. If your book obscures part of the edge of a table, you still perceive the table as a continuous entity. In viewing the environment, we tend to perceive groupings. We see groupings of nearby objects (proximity) or of like objects (similarity). We also perceive objects as complete even though we may only see a part of them (closure), continuous lines rather than broken ones (continuity), and symmetrical patterns rather than asymmetrical ones.

Let's have a closer look at some of the Gestalt principles. Consider what happens when you walk into a familiar room. You perceive that some things stand out (e.g., faces in photographs or posters). Others fade into the background (e.g., undecorated walls and floors). A figure is any object perceived as being highlighted. It is almost always perceived against or in contrast to some kind of receding, unhighlighted (back)ground. Figure 3.19(a) ■ illustrates the concept of **figure-ground**—what stands out from, versus what recedes into, the background. You probably first will notice the light-colored lettering of the word *figure*. We perceive this light-colored lettering as the figure against the darker ground. But if you take a closer look, you can see that the darker surrounding actually depicts the word *ground*.



(a) Proximity (b) Similarity (c) Continuity



(d) Closure (e) Law of Symmetry (f) Law of Prägnanz

■ **Figure 3.18** **The Gestalt Principles of Form Perception.** The Gestalt principles of form perception include perception of figure-ground, (a) proximity, (b) similarity, (c) continuity, (d) closure, (e) symmetry, and (f) law of Präegnanz. Each principle demonstrates the fundamental law of law of Prägnanz, which suggests that through perception, we unify disparate visual stimuli into a coherent and stable whole.

Table 3.2 Gestalt Principles of Visual Perception

The Gestalt principles of proximity, similarity, continuity, closure, and symmetry aid in our perception of forms.

Gestalt Principles	Principle	Figure Illustrating the Principle
Figure-ground	When perceiving a visual field, some objects (figures) seem prominent, and other aspects of the field recede into the background (ground).	Figure 3.19 shows a figure-ground vase, in which one way of perceiving the figures brings one perspective or object to the fore, and another way of perceiving the figures brings a different object or perspective to the fore and relegates the former foreground to the background.
Proximity	When we perceive an assortment of objects, we tend to see objects that are close to each other as forming a group.	In Figure 3.18(a), we tend to see three columns made up of two columns of circles each.
Similarity	We tend to group objects on the basis of their similarity.	In Figure 3.18(b), we tend to see six rows of circles, not six columns of circles.
Continuity	We tend to perceive smoothly flowing or continuous forms rather than disrupted or discontinuous ones.	In Figure 3.18 (c), we perceive a complete letter S even though it is broken up by a rod.
Closure	We tend to perceptually close up, or complete, objects that are not, in fact, complete.	Figure 3.18(d) shows only disjointed, jumbled line segments, which you close up to see a cube.
Symmetry	We tend to perceive objects as forming mirror images about their center.	For example, when viewing Figure 3.18(e), a configuration of assorted brackets, we see the assortment as forming three sets of brackets, rather than six individual items, because we integrate the symmetrical elements into coherent objects.

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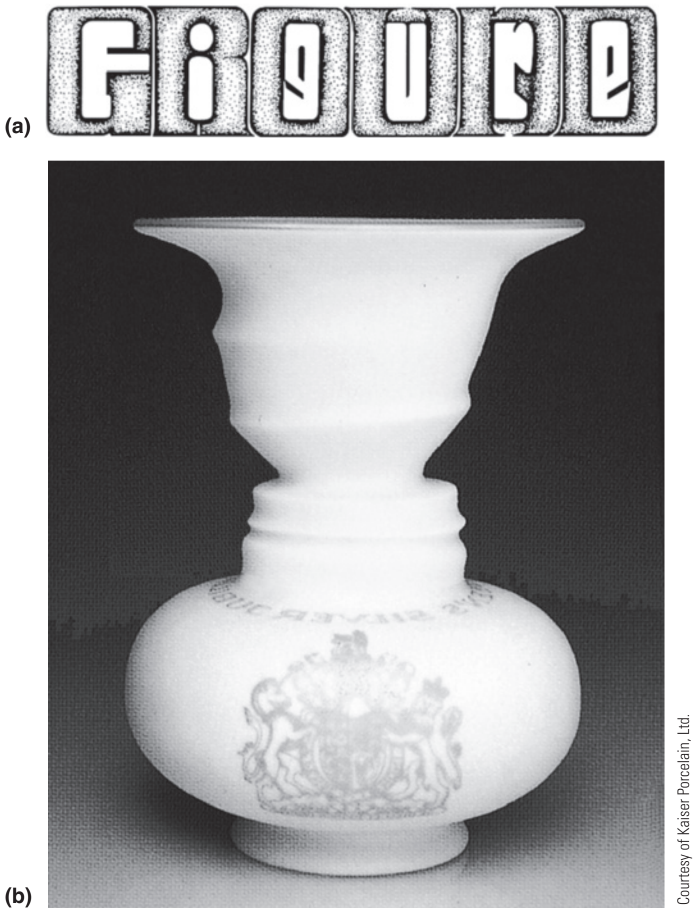

Courtesy of Kaiser Porcelain, Ltd.

■ **Figure 3.19 The Figure-Ground Effect.** In these two Gestalt images, (a) and (b), find which is the figure and which is the ground.

Similarly, in Figure 3.19(b) ■, you can see either a white vase against a black background or two silhouetted faces peering at each other against a white background. It is virtually impossible to see both sets of objects simultaneously. Although you may switch rapidly back and forth between the vase and the faces, you cannot see them both at the same time. One of the reasons suggested as to why each figure makes sense is that both figures conform to the Gestalt principle of *symmetry*. Symmetry requires that features appear to have balanced proportions around a central axis or a central point.

People tend to use Gestalt principles even when they are confronted with novel stimuli. Palmer (1977) showed participants novel geometric shapes that served as targets. He then showed them fragments of the shapes. For each fragment, the participants had to say whether it was part of the original novel geometric shape. Participants were quicker to recognize the fragments as part of the original target if they conformed to Gestalt principles. For example, a triangle exhibits *closure*, in that its three sides form a complete, closed object. A triangle was recognized more quickly as part of the original novel figure than were three line segments that were comparable to the triangle except that they were not closed. They thus did not conform to the Gestalt principle. In sum, we seem to use Gestalt principles in our everyday perception. We use them whether or not the figures to which we apply the principles are familiar.

The Gestalt principles of form perception are remarkably simple. Yet they characterize much of our perceptual organization (Palmer, 1992). Even young infants organize visual stimuli by means of the Gestalt law of proximity (Quinn, Bhatt, & Hayden, 2008). Interestingly, the Gestalt principles appear to apply only to humans and not to other

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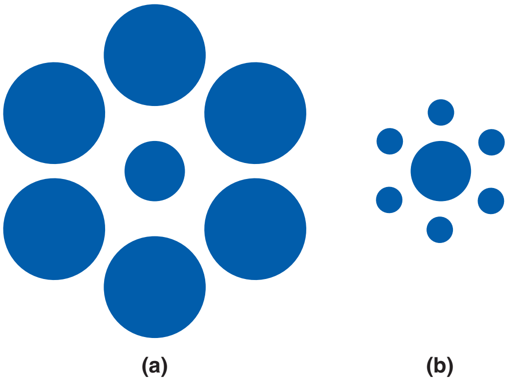


■ **Figure 3.20** **Ebbinghaus Illusion.** Guess which center circle is larger (a or b) and then measure the diameter of each one.

primates. An experiment by Parron and Fagot (2007) showed that only humans misjudged the size of the central circle in the Ebbinghaus illusion (Figure 3.20 ■), whereas baboons did not. Maybe this difference is because humans pay more attention to the surrounding stimuli, whereas baboons concentrate their attention on the central circle.

The Gestalt principles provide valuable descriptive insights into form and pattern perception. But they offer few or no explanations of these phenomena. To understand how or why we perceive forms and patterns, we need to consider explanatory theories of perception.

Recognizing Patterns and Faces

How do we recognize patterns when we look at objects? And are faces a special form of pattern, or is there a special mechanism just for faces? In the next section we explore these and other questions.

Two Different Pattern Recognition Systems

Humans have two systems for recognizing patterns, according to Martha Farah (Farah, 1992, 1995; Farah et al., 1998). The first system specializes in recognizing parts of objects and in assembling those parts into distinctive wholes (*feature analysis system*). For example, when you are in a biology class and notice the elements of a tulip—the stamen, the pistil, and so forth—you look at the flower through this first system. The second system (*configurational system*) specializes in recognizing larger configurations, not analyzing parts of objects or the construction of the objects. For example, if you look at a tulip in a garden and admire its distinctive beauty and form, you look at the flower through the second system.

The second system is most relevant to recognizing faces. When you spot a friend whom you see on a daily basis, you recognize him or her using the configurational system. You are so dependent on this system in everyday life you might not even notice some major change in your friend's appearance, such as his or her having longer hair or having put on new glasses.

The feature analysis system can also be used in face recognition. Suppose you see someone whose face looks vaguely familiar, but you are not sure who it is. You start analyzing features and then realize it is a friend you have not seen for 10 years. In this case, you were able to make the facial recognition only after you analyzed the face by its features. In the end, both configurational and feature analysis may help in making difficult recognitions and discriminations.

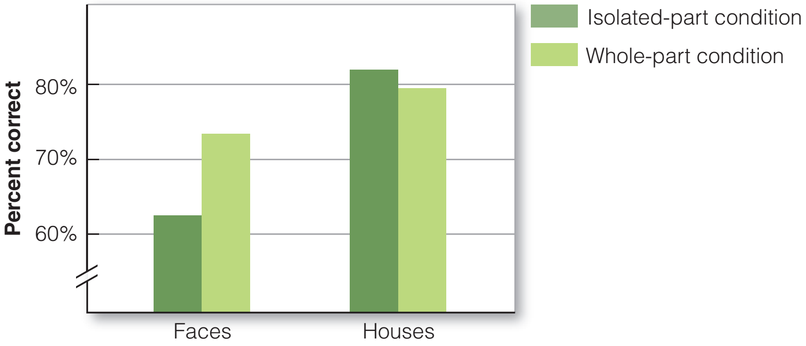
Face recognition occurs, at least in part, in the *fusiform gyrus* of the temporal lobe (Gauthier et al., 2003; Kanwisher, McDermott, & Chun, 1997; Liu, Kanwisher, & Harris, 2010; Tarr & Cheng, 2003). This brain area responds intensely when we look at faces but not when we look at other objects. There is good evidence that there is something special about recognition of faces, even from an early age. For example, infants track movements of a photograph of a human face more rapidly than they track movements of stimuli of similar complexity that are not, however, faces (Farah, 2000a). In one study, experimental participants were shown sketches of two kinds of objects, faces, and houses (Farah et al., 1998). In each case, the face was paired with the name of the person whom the face represented and the house was paired with the name of the house owner. There were six pairings per trial. After learning the six pairings, participants were asked to recognize parts of either the faces or the houses or to recognize the faces or houses as a whole. For example, they might see just a nose or ear, or just a window or a doorway. Or they might see a whole face or house.

If face recognition is somehow special and especially dependent on the second, configurational system, then people should have more difficulty recognizing parts of faces than parts of houses. And this is what the data showed (Figure 3.21 ■): People generally were better at recognizing houses, whether they were presented in parts or in wholes. But more importantly, people had relatively more difficulty in recognizing parts of faces than they had in recognizing whole faces. In contrast, they recognized parts of houses just as well as whole houses. Face recognition, therefore, appears to be special. Presumably, it is especially dependent on the configurational system.

An interesting example of a configurational effect in face recognition occurs when people stare at distorted faces. If you stare at a distorted face for a while and then stare at a normal face, the normal face will look distorted in the opposite direction.

When you look at the faces in Figure 3.22 ■, you will notice that the face in the middle looks normal, whereas the faces to the right and left are gradually more distorted. If you stare at the face to the left, in which the eyes are too close together, for example, and then look back to the normal face in the middle, the eyes in that face will appear too far apart (Leopold et al., 2001; Webster et al., 2004; Zhao & Chubb, 2001). Your knowledge of faces normally tells you what is a normal face and what is a distorted one, but in this case, that knowledge is briefly overridden by your having accustomed yourself to the distorted face.

Cognitive processing of faces and the emotions of the face can interact. Some evidence suggests an age-related "face positivity" effect. In one study, older adults



■ **Figure 3.21** **Recognition of Faces and Houses.** People have more trouble recognizing parts of faces than whole faces. They recognize parts of houses about as well as they recognize whole houses, however.

Source: Based on J.W. Tanaka and M.J. Farah, "Parts and Wholes in Face Recognition," *Quarterly Journal of Experimental Psychology*, 46A, pp. 225–245, Fig. 6.

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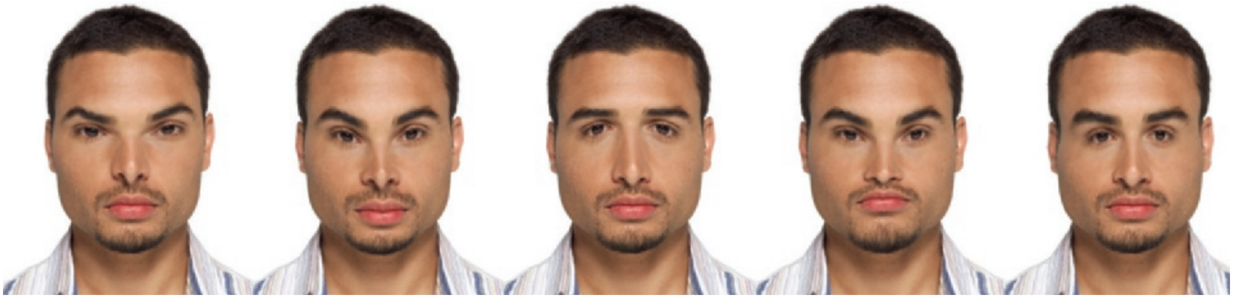

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Figure 3.22 **Normal and Distorted Faces.** Normal (center) and distorted faces.

preferred looking at happy faces and looking away from sad or angry faces (Isaacowitz et al., 2006a, 2006b). Furthermore, happy faces are rated as more familiar than are either neutral or negative faces (Lander & Metcalfe, 2007). But can you choose to ignore the emotion that another person is displaying? Studies indicate that with some negative emotions, such as fear, your amygdala processes the emotion automatically, at least when you do not have to pay much attention to anything else. It is also possible that there is a difference between highly anxious and less anxious individuals: Highly anxious people's amygdalas always process fear automatically, but less anxious people's do not (Palermo & Rhodes, 2007).

The Neuroscience of Recognizing Faces and Patterns

There is evidence that emotion increases activation within the fusiform gyrus when people are processing faces. In one study, participants were shown a face and asked either to name the person or to name the expression. When asked to name the expression, participants showed increased activation of the fusiform gyrus compared with when the participants were asked to name the person (Ganel et al., 2005). The likelihood that emotion is processed in the fusiform gyrus is also supported by studies of people with autism. Patients with autism have impaired emotional recognition. Scanning their brains reveals that the fusiform gyrus is less active than in nonautistic populations.

Patients with autism can learn to identify emotions through an effortful process. However, this training does not facilitate emotion identification as an automatic process, nor does it increase the activation within the fusiform gyrus (Bolte et al., 2006; Hall, Szechtman, & Nahmias, 2003).

Researchers do not all agree that the fusiform gyrus is specialized for face perception, in contrast to other forms of perception. Some believe the fusiform gyrus is the area of the greatest activation in face perception and that other areas also show activation but at lower levels. Similarly, this or other brain areas that respond maximally to faces or anything else may still show some activation when perceiving other objects. In this view, areas of the brain are not all-or-none in what they perceive but, rather, may be differentially activated, in greater or lesser degrees, depending on what is perceived (Haxby et al., 2001; Haxby, Gobbini, & Montgomery, 2004; O'Toole et al., 2005).

Another theory concerning the role of the fusiform gyrus is called the *expert-individuation hypothesis*. According to this theory, the fusiform gyrus is activated when one examines items with which one has visual expertise. Imagine that you are an expert on birds and spend much of your time studying birds. It is expected that you could differentiate among similar birds and would have much practice at such differentiation. As a result, if you are shown five robins, you would likely be able to tell the birds apart. It is unlikely that a person without this expertise could discern among these birds. If your brain were scanned during this activity, activation in the fusiform gyrus, specifically the right one, would be seen. Such activation is seen in people who are experts concerning cars and birds. Even when people are taught to differentiate among similar abstract figures, activation of the fusiform gyrus is observed (Gauthier et al., 1999, 2000; Rhodes et al., 2004; Xu, 2005). This theory is able to account for the activation of the fusiform gyrus when people view faces because we are, in effect, experts at identifying and examining faces.

Prosopagnosia—the inability to recognize faces—implies damage to the configurational system (Damasio, Tranel, & Damasio, 1990; De Renzi Faglioni, Grossi, & Nichelli, 1991; Farah, 2004). Somebody with prosopagnosia can see the face of another person and even recognize whether that person is sad, happy, or angry. But what he fails to recognize is whether that person being observed is a stranger, his friend, or his own mother. The ability to recognize faces is especially influenced by lesions of the right fusiform gyrus, either unilateral or bilateral. Facial memories are affected, in particular, when the bilateral lesions include the right anterior temporal lobe (Barton, 2008). Because they have so much difficulty recognizing faces, people with prosopagnosia may have trouble in other areas of life as well. They may not be able to follow movies because they cannot keep track of the different actors and fail to recognize them when they appear in different scenes of the movie, for example.

People affected by schizophrenia often have trouble recognizing emotions in faces. This difficulty is likely due to the way people with schizophrenia look at others' faces. A healthy person scans faces with their eyes in the shape of an inverted triangle, concentrating on the eyes of the observed person as well as the nose and mouth area. People with schizophrenia tend to look at fewer salient features of a face and also exhibit fewer long fixations (Drusch et al., 2014; Lee et al., 2011).

Other disabilities, such as an early reading disability in which a beginning reader has difficulty in recognizing the features that make up unique words, might stem from damage to the first, element-based system. Moreover, processing can move from one system to another. A typical reader may learn the appearances of words through the first system—element by element—and then come to recognize the words as wholes. Indeed, some forms of reading disability might stem from the inability of the second system to take over from the first.

BELIEVE IT OR NOT

Do Two Different Faces Ever Look the Same to You?

Have you ever noticed that it is easier to recognize faces of people who belong to your own ethnic group? For example, if you are African American, it may be easier for you to recognize and differentiate between black faces than between white or Asian faces. Maybe you thought this was because you are more familiar with the faces you happen to see most often around you and that it is this familiarity that makes it easier for you to discriminate faces similar to your own. But now imagine being told you have a "red" personality. Do you think knowing this would make it easier for you to recognize people who also have a red personality as opposed to a "green" personality (even if they all are of the same race)? Distinguishing among people who belong to your own group and other groups (be it through skin color, personality types, or other characteristics) is a kind of social categorization. Studies have shown that indeed social categorization plays a role in how easy it is for you to recognize faces. As soon as you perceive somebody as an out-group member, it will be harder for you to recognize that person's face. This effect is so stable that it can be elicited by imaginary differences such as red or green personalities or just by adding an African American hairstyle to a white face (Bernstein, Young, & Hugenberg, 2007; Ge et al., 2009; MacLin & Malpass, 2001, 2003).

CONCEPT CHECK

1. What are the major Gestalt principles?
2. What is the "recognition by components" theory?
3. What is the difference between top-down and bottom-up theories of perception?
4. What is the difference between viewer-centered and object-centered perception?
5. What is prosopagnosia?

The Environment Helps You See

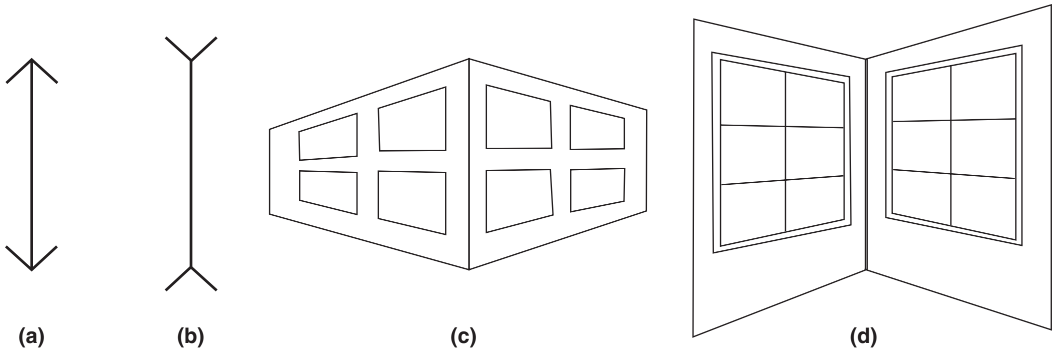
As we have seen, perceptual processes are not so easily completed that the image on your retina can be accepted without further interpretation. Our brain needs to interpret the stimuli it receives and make sense of them. The environment provides cues that help analyze the retinal image and facilitate the construction of a perception that is as close as possible to what is out there in the world—at least, to the extent we can ascertain what is out there. The following part of this chapter explains how we use environmental cues to perceive the world.

Perceptual Constancies

Picture yourself walking to your cognitive psychology class. Two students are standing outside the classroom door. They are chatting as you approach. As you get closer to the door, the amount of space on your retina devoted to images of those students becomes increasingly large. On the one hand, this proximal sensory evidence suggests that the students are becoming larger. On the other hand, you perceive that the students have remained the same size. Why?

The perceptual system addresses variability by analyzing the objects in the perceptual field. Your classmates' perceived constancy in size is an example of perceptual constancy. **Perceptual constancy** occurs when our perception of an object remains the same even when our proximal sensation of the distal object changes (Gillam, 2000). The physical characteristics of the external distal object are probably not changing. But because we must be able to deal effectively with the external world, our perceptual system has mechanisms that adjust our perception of the proximal stimulus. Thus, the perception remains constant although the proximal sensation changes. Here we consider two of the main constancies: size and shape constancies.

Size constancy is the perception that an object maintains the same size despite changes in the size of the proximal stimulus. The size of an image on the retina depends directly on the distance of that object from the eye. The same object at two different distances projects different-size images on the retina. Some striking illusions can be achieved when our sensory and perceptual systems are misled by the same information that usually helps us to achieve size constancy. Judging the sizes of objects accurately is something that we largely have to learn. It is not completely inborn. One study had children and adults of various ages judge the size of a coin displayed at the distance of either 6 or 61 meters and found that children ages 7 to 10 years old as well as adults ages 50 years or older judged the size of the distant coin most accurately. The children ages 5 to 6 years old underestimated the size of the coin, and the young adults overestimated



■ **Figure 3.23** **The Müller-Lyer Illusion.** In this illusion, we tend to view two equally long line segments as being of different lengths. The vertical line segments in panels (a) and (c) appear shorter than the line segments in panels (b) and (d), although they are the same size. Oddly enough, we are not certain why such a simple illusion occurs. Sometimes, the illusion we see in the abstract line segments [panels (a) and (b)] is explained in terms of the diagonal lines at the ends of the vertical segments which may be implicit depth cues similar to the ones we would see in our perceptions of the exterior and interior of a building [panels (c) and (d); Coren & Girgus, 1978].

Source: Based on Coren & Girgus, 1978.

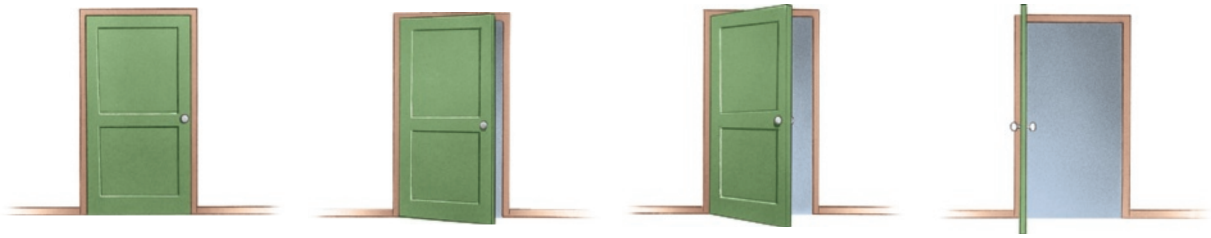
the size. The near coin's size was underestimated by all participants, no matter their age (Kavšek & Granrud, 2012).

An example of size constancy is the Müller-Lyer illusion (Figure 3.23 ■). Here, two line segments that are of the same length appear to be of different lengths. We use shapes and angles from our everyday experience to draw conclusions about the relative sizes of objects. Equivalent image sizes at different depths usually indicate different-size objects.

Studies indicate that the right posterior parietal cortex (involved in the manipulation of mental images) and the right temporo-occipital cortex are activated when people are asked to judge the length of the lines in the Müller-Lyer illusion. The strength of the illusion can be changed by adjusting the angles of the arrows that delimit the horizontal line—the sharper the angles, the more pronounced the illusion. The strength of the illusion is associated with bilateral (on both sides) activation in the lateral (i.e., located on the side of the) occipital cortex and the right superior parietal cortex. As the right intraparietal sulcus (furrow) is activated as well, it seems like there is an interaction of the illusory information with the top-down processes in the right parietal cortex that are responsible for visuospatial judgments (Weidner & Fink, 2007).

Finally, compare the two center circles in the pair of circle patterns in Figure 3.20. Both center circles are actually the same size. But the size of the center circle relative to the surrounding circles affects perception of the center circle's size. ■ Explore Lab 6, the Muller-Lyer Illusion, in CogLab.

Like size constancy, shape constancy relates to the perception of distances but in a different way. *Shape constancy* is the perception that an object maintains the same shape despite changes in the shape of the proximal stimulus (Figure 3.24 ■). An object's perceived shape remains the same despite changes in its orientation and hence in the shape of its retinal image. As the actual shape of the pictured door changes, some parts of the door seem to be changing differentially in their distance from us. It is possible to use neuropsychological imaging to localize parts of the brain that are used in this shape analysis. They are in the extrastriate cortex (Kanwisher et al., 1996, 1997). Points near the outer edge of the door seem to move more quickly toward us than do points near the inner edge. Nonetheless, we perceive that the door remains the same shape. Achieving shape constancy in our perception is easier for us when an object is symmetrical than when it is not because symmetry provides a cue to object orientation (Lee & Saunders, 2013).



■ **Figure 3.24** **Shape Constancy.** Here, you see a rectangular door and doorframe, showing the door as closed, slightly opened, more fully opened, or wide open. Of course, the door does not appear to be a different shape in each panel. Indeed, it would be odd if you perceived a door to be changing shapes as you opened it. Yet, the shape of the image of the door sensed by your retinas does change as you open the door. If you look at the figure, you will see that the drawn shape of the door is different in each panel.

Depth Perception

Consider what happens when you reach for a cup of tea or throw a baseball. You must use information regarding depth. **Depth** is the distance from a surface, usually using your own body as a reference surface when speaking in terms of depth perception. This use of depth information extends beyond the range of your body's reach. When you drive, you use depth to assess the distance of an approaching automobile. When you decide to call out to a friend walking down the street, you determine how loudly to call. Your decision is based on how far away you perceive your friend to be. How do you manage to perceive 3-D space when the proximal stimuli on your retinas account for only a 2-D projection of what you see? You have to rely on depth cues. The next section explores what depth cues are and how we use them.

Depth Cues

Look at the impossible configurations in Figure 3.25 ■. They are confusing because the depth information is contradictory in different sections of the picture. Small segments of these impossible figures look reasonable to us because there is no inconsistency in their individual depth cues (Hochberg, 1978). It is difficult, however, to make sense of

practical applications of **COGNITIVE PSYCHOLOGY**

Depth Cues in Photography

Models and actors often use depth cues of perception to their advantage while being photographed. For example, some models only allow certain angles or orientations to be photographed. A long nose can appear shorter when photographed from slightly below the facial midline (just look closely at some pictures of Barbara Streisand from different angles) because the bridge of the nose recedes slightly into the distance. Also, leaning forward a little can make the upper body appear slightly larger than the lower body, and vice versa for leaning backward. In group pictures, standing slightly behind another person makes you appear smaller; standing slightly in front makes you appear larger. Women's swimsuit designers create optical-illusion swimsuits to enhance different features of the body, making legs appear longer or waists appear smaller and either enhancing or deemphasizing bustlines. Some of these processes to alter perceptions are so basic that many animals have special adaptations designed to make them appear larger (e.g., the fanning peacock tail) or to disguise their identity from predators.

How could you apply perceptual processes to your advantage when having a photo taken or when dressing for a party?

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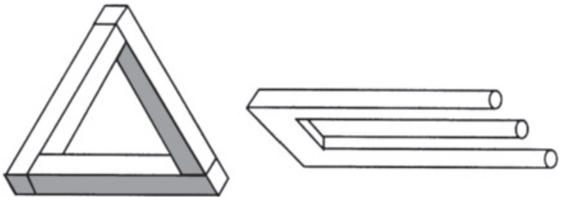
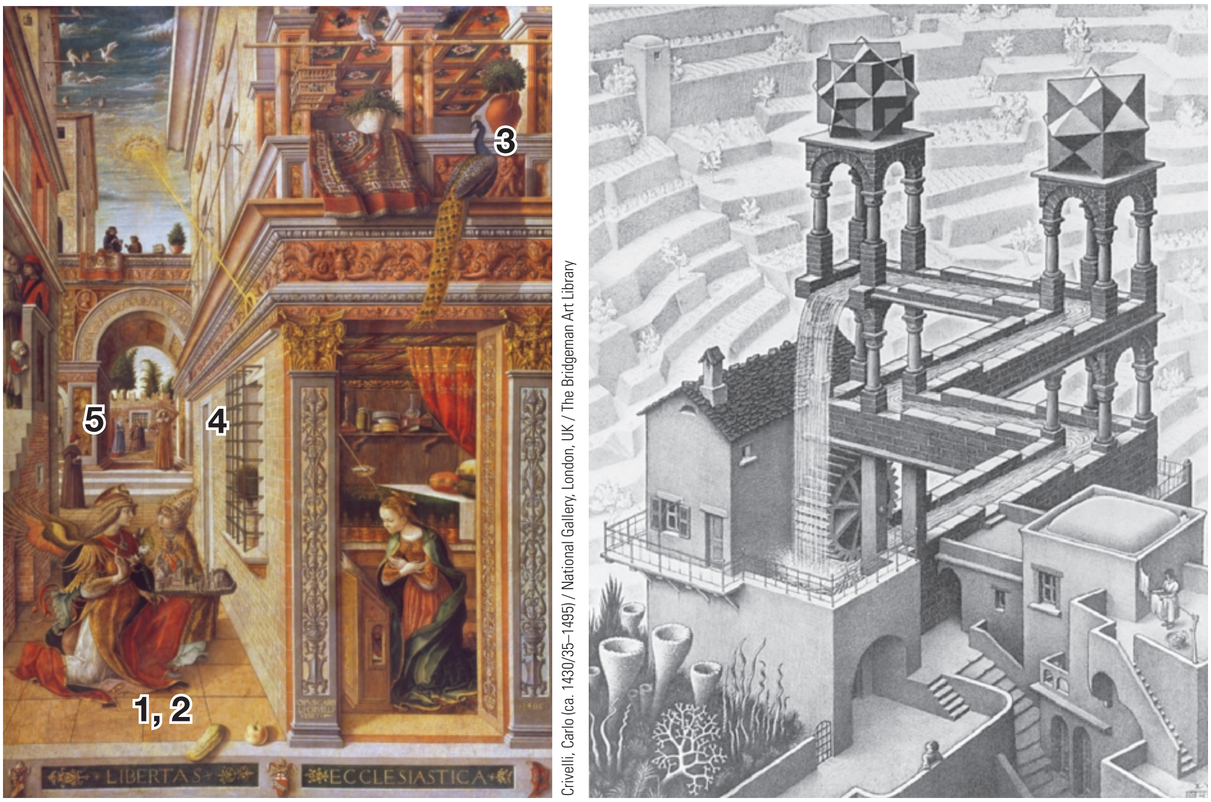
the figure as a whole. The reason is that the cues providing depth information in various segments of the picture are in conflict.

Generally, depth cues are either monocular (*mon-*, *one*; *ocular*, *related to the eye*) or binocular (*bin-*, *both*, *two*). **Monocular depth cues** can be represented in just two dimensions and observed with just one eye. Figure 3.26 ■ illustrates several of the monocular depth cues defined in Table 3.3 ■. They include texture gradients, relative size, interposition, linear perspective, aerial perspective, location in the picture plane, and motion parallax. Before you read about the cues in either the table or the figure caption,



■ **Figure 3.25 Impossible Figures.** What cues may lead you to perceive these impossible figures as entirely plausible?



Crivelli, Carlo (ca. 1430/35–1495) / National Gallery, London, UK / The Bridgeman Art Library

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(a) **(b)**

■ **Figure 3.26 Depth Cues.** In *The Annunciation* (left), Carlo Crivelli masterfully illustrated at least five monocular depth cues: (1, 2) Texture gradients and relative size: The floor tiles appear similar both in front of and behind the figures in the forefront of the corridor, but the tiles at the front of the corridor are larger and are spread farther apart than the tiles at the rear. (3) Interposition: The peacock partially blocks our view of the frieze on the wall to the right of the corridor. (4) Linear perspective: The sides of the wall seem to converge inward toward the rear of the corridor. (5) Location in the picture plane: The figures at the rear of the corridor are depicted higher in the picture plane than are the figures at the front of the corridor. M. C. Escher used his mastery of visual perception to create paradoxical depictions, such as in his drawing *Waterfall* (right). Make a list of the various monocular depth cues in *Waterfall* that lead us to perceive the impossible.

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look just at the figure. See how many depth cues you can decipher simply by observing the figure carefully.

Table 3.3 also describes motion parallax, the only monocular depth cue not shown in the figure. Motion parallax requires movement. Thus, it cannot be used to judge depth within a stationary image, such as a picture. Another means of judging depth involves **binocular depth cues**, based on the receipt of sensory information in three dimensions from both eyes (Parker, Cumming, & Dodd, 2000). Table 3.3 also summarizes some of the binocular cues used in perceiving depth.

Binocular depth cues use the relative positioning of your eyes. Your two eyes are positioned far enough apart to provide two kinds of information to your brain: binocular disparity and binocular convergence. In *binocular disparity,* your two eyes send increasingly disparate (differing) images to your brain as objects approach you. Your brain interprets the degree of disparity as an indication of distance from you. In addition, for objects we view at relatively close locations, we use depth cues based on binocular convergence. In *binocular convergence,* your two eyes increasingly turn inward as objects approach you. Your brain interprets these muscular movements as indications of distance from you.

In about 8% of people whose eyes are not aligned properly (strabismic eyes), depth perception can occur even with just one eye. Usually people with strabismic eyes have a sensitive zone in their retina other than the fovea that captures a part of the space that

Table 3.3 **Monocular and Binocular Cues for Depth Perception**

Various perceptual cues aid in our perception of the 3-D world. Some of these cues can be observed by one eye alone; other cues require the use of both eyes.

Cues for Depth Perception	Appears Closer	Appears Farther Away
Monocular Depth Cues		
Texture gradients	Larger grains, farther apart	Smaller grains, closer together
Relative size	Bigger	Smaller
Interposition	Partially obscures other object	Is partially obscured by other object
Linear perspective	Apparently parallel lines seem to diverge as they move away from the horizon	Apparently parallel lines seem to converge as they approach the horizon
Aerial perspective	Images seem crisper, more clearly delineated	Images seem fuzzier, less clearly delineated
Location in the picture plane	Above the horizon, objects are higher in the picture plane; below the horizon, objects are lower in the picture plane	Above the horizon, objects are lower in the picture plane; below the horizon, objects are higher in the picture plane
Motion parallax	Objects approaching get larger at an ever-increasing speed (i.e., big and moving quickly closer)	Objects departing get smaller at an ever-decreasing speed (i.e., small and moving slowly farther away)
Binocular Depth Cues		
Binocular convergence	Eyes feel tug inward toward nose	Eyes relax outward toward ears
Binocular disparity	Huge discrepancy between image seen by left eye and image seen by right eye	Minuscule discrepancy between image seen by left eye and image seen by right eye

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should have been captured were the eyes properly aligned. This capacity normally goes along with a partial inhibition of signals from the fovea. If the fovea stays sensitive, however, those people produce double images, which can be fused and result in stereoscopic vision with just one eye (Rychkova & Ninio, 2009).

Depth perception may depend on more than just the distance or depth at which an object is located relative to oneself. The perceived distance to a target is influenced by the effort required to walk to the location of the target (Proffitt et al., 2003, 2006). People with a heavy backpack perceive the distance to a target location as farther than those not wearing a heavy backpack. In other words, there can be an interaction between the perceptual result and the perceived effort required to reach the object perceived (Wilt, Proffitt, & Epstein, 2004). The more effort one requires to reach something, the farther away it is perceived to be.

Depth perception is a good example of how cues facilitate our perception. When we see an object that appears small, there is no automatic reason to believe it is farther away. Rather, the brain uses this contextual information to conclude that the smaller object is farther away.

INVESTIGATING COGNITIVE PSYCHOLOGY

Binocular Depth Cues

You can test the differing perspectives in binocular disparity by holding your finger about an inch from the tip of your nose. Look at it first with one eye covered, then the other: It will appear to jump back and forth. Now do the same for an object 20 feet away, then 100 yards away. The apparent jumping, which indicates the amount of binocular disparity, will decrease with distance. Your brain interprets the information regarding disparity as a cue indicating depth.

The Neuroscience of Depth Perception

Figure 3.27 ■ illustrates how binocular disparity and binocular convergence work. The brain contains neurons that specialize in the perception of depth. These neurons, as one might expect, are referred to as *binocular neurons.* The neurons integrate incoming information from both eyes to form information about depth. The binocular neurons are found in the visual cortex (Parker, 2007).

Research on both nonhuman animals and humans has shown that visual shape is processed in the ventral visual stream as well as important visual areas, such as the lateral occipital cortex and the ventral temporal cortex. After the initial processing in the primary visual cortex, moving 3-D shapes are processed in the human motion complex (hMT), an area that is concerned with motion processing. Next to be processed are depth and shape information. This processing occurs mainly in the V5 region of the visual cortex; the medial parietal cortex also may participate in the processing to some extent. In the next step, different features of the stimulus are analyzed in the lateral occipital cortex to infer the shape from the moving object. The shape that was inferred is then compared with the shape representation in the ventral occipital and ventral temporal areas of the cortex. The process ends with activation in the parietal cortex and primary visual cortex, which suggests that the parietal cortex is involved in top-down processes that influence the areas in the primary visual cortex where the visual stimuli are being processed in the beginning (Jiang et al., 2008; Orban et al., 2003).

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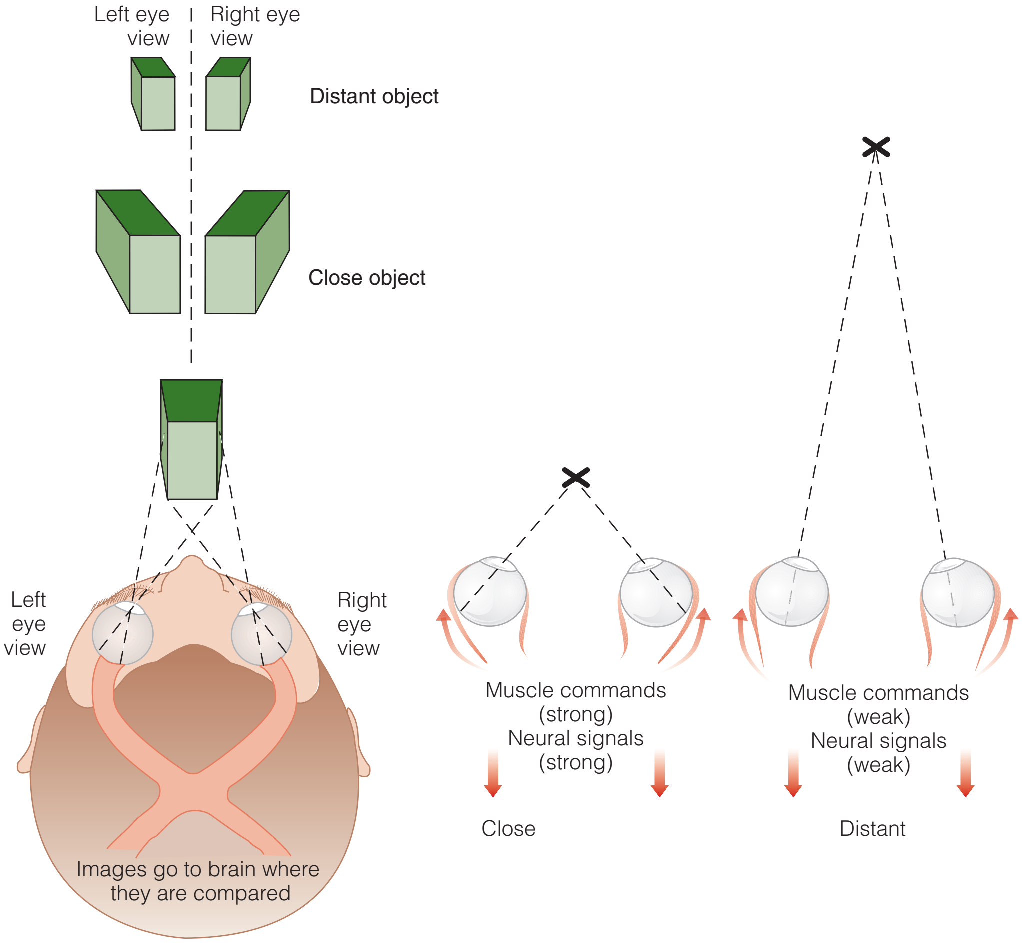
Left eye view
Right eye view
Distant object
Close object
Left eye view
Right eye view
Images go to brain where they are compared
Muscle commands (strong)
Neural signals (strong)
Close
Muscle commands (weak)
Neural signals (weak)
Distant

(a) Binocular disparity **(b) Binocular convergence**

■ **Figure 3.27 Binocular Disparity and Convergence.** (a) Binocular disparity: The closer an object is to you, the greater the disparity between the views of it as sensed in each of your eyes. (b) Binocular convergence: Because your two eyes are in slightly different places on your head, when you rotate your eyes so that an image falls directly on the central part of your eye, in which you have the greatest visual acuity, each eye must turn inward slightly to register the same image. The closer the object you are trying to see, the more your eyes must turn inward. Your muscles send messages to your brain regarding the degree to which your eyes are turning inward, and these messages are interpreted as cues indicating depth.

Deficits in Perception

Clearly, cognitive psychologists learn a great deal about normal perceptual processes by studying perception in normal participants. Additionally, however, we often gain understanding of perception by studying people whose perceptual processes differ from the norm (Farah, 1990; Weiskrantz, 1994).

Agnosias and Ataxias

Perceptual deficits provide an excellent way to test hypotheses with regard to how the perceptual system works. Remember that there are two distinct visual pathways, one for

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identifying objects (*what*), the other for pinpointing where objects are located in space and how to manipulate them (*where* or *how*).

The *what–how hypothesis* is best supported by evidence of processing deficits: Deficits can impair people's ability to recognize *what* they see and can impair people's ability to reach for what they see (*how*).

Difficulties Perceiving the "What"

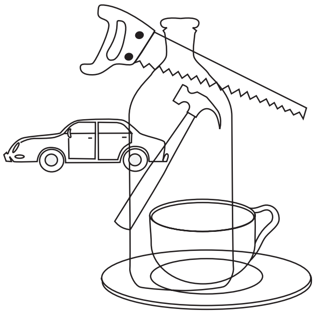
Consider first the *what*. People who suffer from an **agnosia** have trouble perceiving sensory information (Moscovitch, Winocur, & Behrmann, 1997). Agnosias often are caused by damage to the border of the temporal and occipital lobes (Farah, 1990, 1999) or restricted oxygen flow to areas of the brain, sometimes as a result of traumatic brain injury (Zoltan, 1996). There are many kinds of agnosias. Not all of them are visual. Here, we focus on a few specific inabilities to see forms and patterns in space.

Generally, people with agnosia have normal sensations of what is in front of them. They can perceive the colors and shapes of objects and persons, but they cannot recognize what the objects are. They have trouble with the *what* pathway.

People who suffer from visual-object agnosia can see all parts of the visual field, but the objects they see do not mean anything to them (Kolb & Whishaw, 1985). For example, one agnosic patient, on seeing a pair of eyeglasses, noted first that there was a circle, then that there was another circle, then that there was a crossbar, and finally guessed that he was looking at a bicycle. A bicycle does, indeed, include two circles and a crossbar (Luria, 1973).

Disturbance in the temporal region of the cortex can lead to *simultagnosia*. In simultagnosia, an individual is unable to pay attention to more than one object at a time. A person with simultagnosia would not see each of the objects depicted in Figure 3.28 ■. Rather, the person might report seeing the hammer but not the other objects (Williams, 1970).

Prosopagnosia results in a severely impaired ability to recognize human faces (Farah et al., 1995; Feinberg et al., 1994; McNeil & Warrington, 1993; Young, 2003). A person with prosopagnosia might not recognize her or his own face in the mirror. This fascinating disorder has spawned much research on face identification, a popular topic in visual perception (Damasio, 1985; Farah et al., 1995; Farah, Levinson, & Klein, 1995; Haxby et al., 1996). The functioning of the right-hemisphere fusiform gyrus is strongly implicated in prosopagnosia. In particular, the disorder is associated with damage to the right temporal lobe of the brain. Prosopagnosia, in particular, and agnosia, in general, are obstacles that persist over time. In one particular case, a woman who sustained carbon-monoxide toxicity began to suffer from agnosia, including prosopagnosia. After 40 years, this woman was reevaluated and still demonstrated these deficits. These findings reveal the lasting nature of agnosia (Sparr et al., 1991).



■ **Figure 3.28 Simultagnosia.** When you view this figure, you see various objects overlapping. People with simultagnosia cannot see more than one of these objects at any one time.

Source: Based on *Sensation and Perception* by Stanley Coren and Lawrence M. Ward, copyright © 1989 by Harcourt Brace & Company.

Difficulties in Knowing the "How"

A different kind of perceptual deficit is associated with damage to the *how* pathway. This deficit is **optic ataxia**, which is an impaired ability to use the visual system to guide movement (Borchers et al., 2013). People with this deficit have trouble reaching for things. All of us have had the experience of coming home at night and trying to find the keyhole in the front door. It's too dark to see, and we have to grope with our key for the keyhole, often taking a while to find it. Someone with optic ataxia has this problem even with a fully lit visual field. The *how* pathway is impaired.

Ataxia results from a processing failure in the posterior parietal cortex, where sensorimotor information is processed. It is assumed that higher-order processes are

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involved because most patients' disorders are complex, and they can indeed grasp objects under certain circumstances (Jackson et al., 2009). People with ataxia can improve their movements toward a visible aim when they hold off with their movements for a few seconds. Immediate movements are executed through dorsal-stream processing, whereas delayed movements make use of the ventral system, including the occipitotemporal and temporoparietal areas (Himmelbach et al., 2009; Milner et al., 2003; Milner & Goodale, 2008).

Are Perceptual Processes Independent of Each Other?

When we consider the different kinds of perceptual deficits, it is stunning to see how specific they are. Some people cannot name colors; others cannot recognize movement or faces. Others can see a mug on the table in front of them, yet cannot grasp the mug. This kind of extreme specificity of deficits leads to questions about specialization (modular processes). Specifically, are there distinct processing centers or modules for particular perceptual tasks, such as for color or face recognition? This question goes beyond the separation of perceptual processes along different sensory modalities (e.g., the differences between visual and auditory perception). Modular processes are those that are specialized for particular tasks. They may involve only visual processes (as in color perception), or they may involve an integration of visual and auditory processes (as in certain aspects of speech perception that are discussed in Chapter 10). For face perception (or any perceptual process) to be considered a truly modular process, we would need to have further evidence that the process is domain specific and, therefore, uses only specific kinds of information, and that information does not freely flow across different modules. That is, other perceptual processes should not contribute to, interfere with, or share information with face perception.

Anomalies in Color Perception

Color perception deficits are much more common in men than in women, and they are genetically linked. However, they can result from lesions to the ventromedial occipital and temporal lobes.

There are several kinds of color deficiency, which are sometimes referred to as kinds of "color blindness." Least common is *rod monochromacy,* also called *achromacy.* People with this condition have no color vision at all. It is the only true form of pure color blindness. In this condition the cones are nonfunctional. They see only shades of gray as a function of their vision through the rods of the eye.

Most people who suffer from deficits in color perception can still see some color, despite the name color blindness. In *dichromacy*, only two of the mechanisms for color perception work, and one is malfunctioning. The result of this malfunction is one of three types of color blindness (color-perception deficits). The most common is red-green color blindness. People with this form of color-blindness have difficulty in distinguishing red from green although they may be able to distinguish, for example, dark red from light green (*Visual disabilities: Color-blindness,* 2004). The extreme form of red-green color blindness is called *protanopia*. The other types of color blindness are *deuteranopia* (trouble seeing greens with symptoms similar to protanopia) and *tritanopia* (confusion of blues and greens, and yellows that disappear or appear as light shades of reds). Figure 3.29 ■ shows test plates that are commonly used to detect anomalies in color perception.

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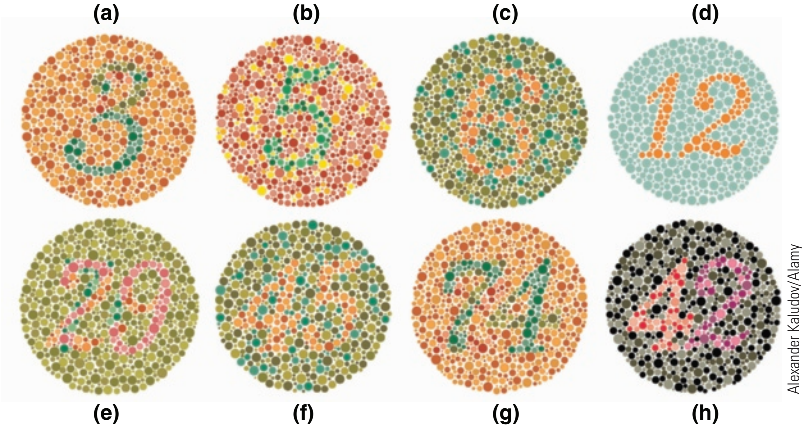

Alexander Kaludov/Alamy

Figure 3.29 Ishihara test plates are often used to detect anomalies in color perception. Individuals with normal color vision should be able to see the following numbers: a) 3, b) 5, c) 6, d) 12, e) 29, f) 45, g) 74, and h) 42. Individuals with red-green color deficiencies see: a) 5, b) no number, c) no number, d) 12, e) 70, f) no number, g) 21, and h) 2 or 4.

CONCEPT CHECK

1. What is shape constancy?
2. What are the main cues for depth perception?
3. What is visual agnosia?
4. What is the difference between monochromacy and dichromacy?

Why Does It Matter? Perception in Practice

Perceptual processes and change blindness play a significant role in accidents and efforts at accident prevention. About 50% of all collision accidents are a result of missing or delayed perception (Nakayama, 1978). Especially two-wheeled vehicles are often involved in "looked-but-failed-to-see" accidents, in which the driver of the involved car states that he did indeed look in the direction of the cyclist but failed to see the approaching motorcycle (Clabaux et al., 2012). It is possible that drivers develop a certain "scanning" strategy that they use in complex situations, such as at crossroads. The scanning strategy concentrates on the most common and dangerous threats but fails to recognize small deviations, or more uncommon objects like two-wheeled vehicles. In addition, people tend to fail to recognize new objects after blinking and saccades (fast movements of both eyes in one direction).

Generally, people are not aware of the danger of change blindness and believe that they will be able to see all obstacles when looking in a particular direction ("change blindness blindness"; Davis et al., 2008; Simons & Rensink, 2005). We will discuss change blindness in more detail in Chapter 4. This tendency has implications for the education of drivers with regard to their perceptual abilities. It also has implications for the design of traffic environments, which should be laid out in a way that facilitates complex traffic flow and makes drivers aware of unexpected obstacles, such as bicycles (Galpin, Underwood, & Crundall, 2009; Koustanai et al., 2008).

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Key Themes

Several key themes, as outlined in Chapter 1, emerge in our study of perception.

Rationalism versus empiricism. How much of the way we perceive can be understood as due to some kind of order in the environment that is relatively independent of our perceptual mechanisms? In the Gibsonian view, much of what we perceive derives from the structure of the stimulus, independent of our experience with it. In contrast, in the view of constructive perception, we construct what we perceive. We build up mechanisms for perceiving based on our experience with the environment. As a result, our perception is influenced at least as much by our intelligence (rationalism) as it is by the structure of the stimuli we perceive (empiricism).

Basic versus applied research. Research on perception has many applications, such as in understanding how we can construct machines that perceive. The U.S. Postal Service relies heavily on machines that read ZIP codes. To the extent that the machines are inaccurate, there is a risk of mail going astray. These machines cannot rely on strict template matching because people write numbers in different ways. So the machines must do at least some feature analysis.

Another application of perception research is in human factors. Human-factors researchers design machines and user interfaces to be user-friendly. An automobile driver or airplane pilot sometimes needs to make split-second decisions. The cockpits thus must have instrument panels that are well lit, easy to read, and accessible for quick action. Basic research on human perception can inform developers what user-friendly means.

Domain generality versus domain specificity. Perhaps nowhere is this theme better illustrated than in research on face recognition. Is there something special about face recognition? It appears so. Yet many of the mechanisms that are used for face recognition are used for other kinds of perception as well. Thus, it appears that perceptual mechanisms may be mixed—some general across domains, others specific to domains such as face recognition.

SUMMARY

1. **How can we perceive an object, such as a chair, as having a stable form given that the image of the chair on our retina changes as we look at it from different directions?** Perceptual experience involves four elements: distal object, informational medium, proximal stimulation, and perceptual object. Proximal stimulation is constantly changing because of the variable nature of the environment and physiological processes designed to overcome sensory adaptation. Perception therefore must address the fundamental question of constancy.

   Perceptual constancies (e.g., size and shape constancy) result when our perceptions of objects tend to remain constant. That is, we see constancies even as the stimuli registered by our senses change. Some perceptual constancies may be governed by what we know about the world. For example, we have expectations regarding how rectilinear structures usually appear. But constancies also are influenced by invariant relationships among objects in their environmental context.

   One reason we can perceive 3-D space is the use of binocular depth cues. Two such cues are binocular disparity and binocular convergence. Binocular disparity is based on the fact that each of two eyes receives a slightly different image of the same object as it is being viewed. Binocular convergence is based on the degree to which our two eyes must turn inward toward each other as objects get

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closer to us. We also are aided in perceiving depth by monocular depth cues. These cues include texture gradients, relative size, interposition, linear perspective, aerial perspective, height in the picture plane, and motion parallax. One of the earliest approaches to form and pattern perception is the Gestalt approach to form perception. The Gestalt law of Prägnanz has led to the explication of several principles of form perception. These principles include figure-ground, proximity, similarity, closure, continuity, and symmetry. They characterize how we perceptually group together various objects and parts of objects.

2. **What are two fundamental approaches to explaining perception?** Perception is the set of processes by which we recognize, organize, and make sense of stimuli in our environment. It may be viewed from either of two basic theoretical approaches: constructive or direct perception. The viewpoint of constructive (or intelligent) perception asserts that the perceiver essentially constructs or builds up the stimulus that is perceived. He or she does so by using prior knowledge, contextual information, and sensory information. In contrast, the viewpoint of direct perception asserts that all the information we need to perceive is in the sensory input (such as from the retina) that we receive.

   An alternative to both of these approaches integrates features of each. It suggests that perception may be more complex than direct-perception theorists have suggested, yet perception also may involve more efficient use of sensory data than constructive-perception theorists have suggested. Specifically, a computational approach to perception suggests that our brains compute 3-D perceptual models of the environment based on information from the 2-D sensory receptors in our retinas.

   The main bottom-up theoretical approaches to pattern perception include template-matching theories and feature-matching theories. Some support for feature-matching theories comes from neurophysiological studies identifying what are called *feature detectors* in the brain. It appears that various cortical neurons can be mapped to specific receptive fields on the retina. Differing cortical neurons respond to different features. Examples of such features are line segments or edges in various spatial orientations. Visual perception seems to depend on three levels of complexity in the cortical neurons. Each level of complexity seems to be further removed from the incoming information from the sensory receptors. Another bottom-up approach, the recognition-by-components (RBC) theory, more specifically delineates a set of features involved in form and pattern perception.

   Bottom-up approaches explain some aspects of form and pattern perception. Other aspects require approaches that suggest at least some degree of top-down processing of perceptual information. For example, top-down approaches better but incompletely explain such phenomena as context effects, including the object-superiority effect and the word-superiority effect.

3. **What happens when people with normal visual sensations cannot perceive visual stimuli?** Agnosias, which are usually associated with brain lesions, are deficits of form and pattern perception. They cause afflicted people to be insufficiently able to recognize objects that are in their visual fields, despite normal sensory abilities. People who suffer from visual-object agnosia can sense all parts of the visual field. But the objects they see do not mean anything to them. Individuals with simultagnosia are unable to pay attention to more than one object at a time. People with spatial agnosia have severe difficulty in comprehending and handling the relationship between their bodies and the spatial configurations of the world around them. People with prosopagnosia have severe impairment in their ability to recognize human faces, including their

own. These deficits lead to the question of whether specific perceptual processes are modular—specialized for particular tasks. Color blindness is another type of perceptual deficit.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Briefly describe each of the monocular and binocular depth cues listed in this chapter.
2. Describe bottom-up and top-down approaches to perception.
3. How might deficits of perception, such as agnosia, offer insight into normal perceptual processes?
4. Compare and contrast the Gestalt approach to form perception and the theory of direct perception.
5. Design a demonstration that would illustrate the phenomenon of perceptual constancy.
6. Design an experiment to test the feature-matching theory.
7. To what extent does perception involve learning? Why?

KEY TERMS

agnosia, p. 111
binocular depth cues, p. 108
bipolar cells, p. 80
bottom-up theories, p. 81
cones, p. 80
constructive perception, p. 91
context effects, p. 92
depth, p. 106
direct perception, p. 82
feature-matching theories, p. 85
figure-ground, p. 97
fovea, p. 78
ganglion cells, p. 80
Gestalt approach to form perception, p. 97
landmark-centered, p. 97
law of Prägnanz, p. 97
monocular depth cues, p. 107
object-centered representation, p. 96
optic ataxia, p. 111
optic nerve, p. 80
percept, p. 77
perception, p. 72
perceptual constancy, p. 104
photo pigments, p. 79
photoreceptors, p. 79
recognition-by-components (RBC) theory, p. 90
retina, p. 78
rods, p. 79
templates, p. 84
top-down theories, p. 81
viewer-centered representation, p. 96

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 14—Blind Spot
Lab 3—Apparent Motion
Lab 16—Metacontrast Masking
Lab 6—Müller-Lyer Illusion
Lab 1—Signal Detection
Lab 7—Visual Search
Lab 42—Lexical Decision

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4

Attention and Consciousness

CHAPTER OUTLINE

The Nature of Attention and Consciousness
Attention
- Attending to Signals over the Short and Long Terms
  - Signal Detection: Finding Important Stimuli in a Crowd
  - Vigilance: Waiting to Detect a Signal
- Search: Actively Looking
  - Feature-Integration Theory
  - Similarity Theory
  - Neuroscience: Aging and Visual Search
- Selective Attention
  - What Is Selective Attention?
  - Theories of Selective Attention
  - Neuroscience and Selective Attention
- Divided Attention
  - Investigating Divided Attention in the Lab
  - Theories of Divided Attention
  - Divided Attention in Everyday Life
- Factors That Influence Our Ability to Pay Attention
- Neuroscience and Attention: A Network Model

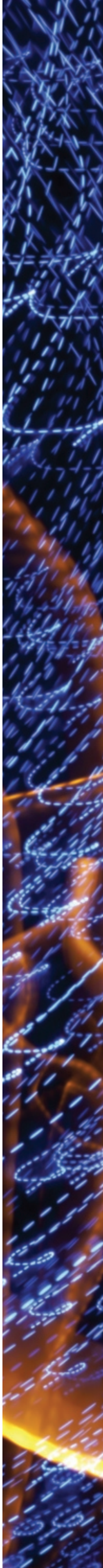
When Our Attention Fails Us
- Attention Deficit Hyperactivity Disorder
- Change Blindness and Inattentional Blindness
- Spatial Neglect—One Half of the World Goes Amiss

Automatic and Controlled Processes in Attention
- Automatic and Controlled Processes
- How Does Automatization Occur?
- Automatization in Everyday Life
- Mistakes We Make in Automatic Processes

Consciousness
- The Consciousness of Mental Processes
- Preconscious Processing
  - Studying the Preconscious—Priming
  - What's That Word Again? The Tip-of-the-Tongue Phenomenon
  - When Blind People Can See

Key Themes
Summary
Thinking about Thinking: Analytical, Creative, and Practical Questions
Key Terms
Media Resources

■ **CogLab** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. Can we actively process information even if we are not aware of doing so? If so, what do we process and how?
2. What are some of the functions of attention?
3. What are some theories cognitive psychologists have developed to explain attentional processes?
4. What have cognitive psychologists learned about attention by studying the human brain?

BELIEVE IT OR NOT

Does Paying Attention Enable You to Make Better Decisions?

So you've got an important decision to make? People usually are taught to deliberate carefully upon the more complex decisions in their lives. Sometimes, however, unconsciously made decisions can be better than carefully deliberated ones.

Ap Dijksterhuis et al. (2006) conducted experiments in which participants had to choose the best from four cars and other objects such as toothpaste. The complexity of the decision depended on the number of important attributes that described the object. Participants were best able to make a simple decision, such as the one for toothpaste (which was based on two attributes), when they deliberated about their choices. However, when participants had to choose the best of four cars (described by 12 attributes each), they fared much better when they were not given the chance consciously to think about their choices.

Conscious choices can be flawed because we do not have unlimited mental capacity. At some point, we have to cut down on the amount of information we will consider. Also, when consciously thinking about alternatives, we sometimes attach more importance to less relevant attributes, which can lead to suboptimal choices. So next time you have a complex decision to make, it may be best to just sit back, relax, and let the decision come to you. This chapter introduces you to attention and consciousness and how cognitive psychologists approach them (see also the description of the work of Gerd Gigerenzer on fast and frugal heuristics in Chapter 12).

Let's examine what it means to pay attention in an everyday situation. Imagine driving in rush hour, near a major sports stadium where an event is about to start. The streets are filled with cars, some of them honking. At some intersections the police are regulating the traffic but not in synchrony with the traffic lights. This asynchronicity—with the traffic light signaling one thing and the police signaling another—divides your attention. Also, thousands of people are streaming through the streets to attend the sports event. You need to pay close attention to the traffic light as well as the officer on the road, the cars passing by, and the pedestrians that might unexpectedly cross the street. What is it that lets us pay attention to so many different moving parts in traffic? What lets us shift attention if a pedestrian suddenly walks out into the street without notice? And why does our attention sometimes fail us, occasionally with drastic consequences such as a car accident? This chapter will explore our amazing capability to pay attention, divide our attention, and select stimuli to which to pay attention in detail.

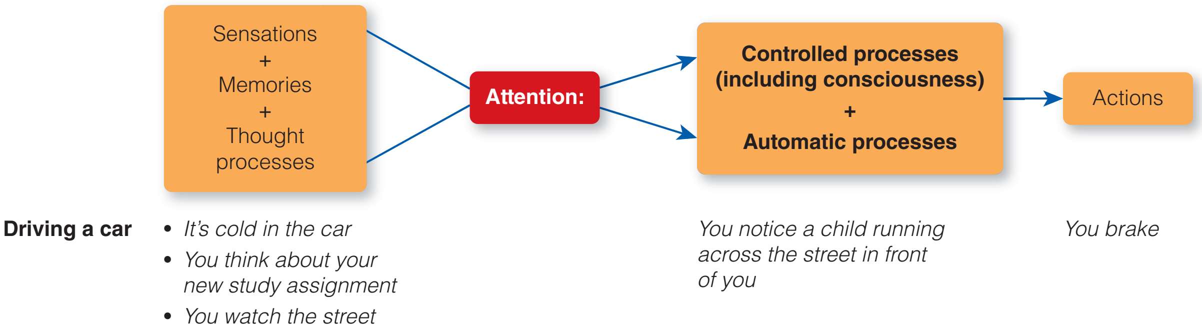
The Nature of Attention and Consciousness

> *[Attention] is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thoughts. . . . It implies withdrawal from some things in order to deal effectively with others.*
>
> —William James, *Principles of Psychology*

Attention is the means by which we actively select and process a limited amount of information from all of the information captured by our senses, our stored memories, and our other cognitive processes (De Weerd, 2003a; Rao, 2003). Attention includes both conscious and unconscious processes (Nobre & Kastner, 2014). In many cases, conscious processes are relatively easy for researchers to study. Unconscious processes are harder to study, simply because you are not conscious of them (Jacoby, Lindsay, & Toth, 1992; Merikle, 2000). For example, you always have a wealth of information available to you that you are not even aware of until you retrieve that information from your memory or shift your attention toward it. You probably can remember where you slept when you were 10 years old or where you ate your breakfasts when you were 12 years old. Extensive sensory information is also available to you at any given time, but you do not attend to it. After all, if you attended to each and every detail of your environment, you would feel quickly overwhelmed (Figure 4.1 ■). You also have little reliable information about what happens when you sleep. Therefore, it is hard to study processes that are hidden somewhere in your unconsciousness, and of which you are not aware.

Attention allows us to use our limited mental resources judiciously (Goleman, 2013). We can focus more on the stimuli that interest us by focusing less on outside stimuli (sensations) and inner stimuli (thoughts and memories) that are not of interest to us. This heightened focus increases the likelihood that we can respond speedily and accurately to interesting stimuli. Heightened attention also paves the way for memory processes. We are more likely to remember information to which we paid attention than information we ignored.

At one time, psychologists believed that attention was the same thing as consciousness. Now they acknowledge that we attend to and process some sensory information and memories without our conscious awareness (Bahrami et al., 2008; Shear, 1997).


Sensations
+
Memories
+
Thought processes
Attention:
Controlled processes (including consciousness)
+
Automatic processes
Actions
Driving a car
• It's cold in the car
• You think about your new study assignment
• You watch the street
You notice a child running across the street in front of you
You brake

■ **Figure 4.1** **How Does Attention Work?** At any point in time, we perceive a lot of sensory information. Through attentional processes (which can be automatic or controlled), we filter out the information that is relevant to us and that we want to attend to. Eventually, this filtering leads to our taking action on the basis of the information we attended to.

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Consciousness includes both the feeling of awareness and the content of awareness, some of which may be under the focus of attention (Bourguignon, 2000; Farthing, 1992, 2000; Taylor, 2002). Attention and consciousness, therefore, form two partially overlapping sets (Srinivasan, 2008; DiGirolamo & Griffin, 2003). For example, writing your name requires little conscious awareness. You may write it while consciously engaged in other activities. In contrast, writing a name that you have never encountered requires attention to the sequence of letters.

Conscious attention plays a causal role in cognition, and serves three purposes. First, it helps monitor our interactions with the environment. We maintain our awareness of how well we are adapting to a situation. Second, it assists us in linking our past (memories) and our present (sensations) to give us a sense of continuity of experience. Such continuity may even serve as the basis for personal identity. Third, it helps us control and plan for our future actions based on the information from monitoring and from the links between past memories and present sensations (Posner, 2011).

In this chapter, we will first explore different kinds of attention such as vigilance, search, selective attention, and divided attention. Afterward, we will consider what happens when our attention does not work properly, and what strategies we use to avoid getting overwhelmed in a world that is full of sensory stimuli. Then, we will explore the nature of automatic processes, which help humans to make the best use of their attentional resources. Last but not least, we will consider the topic of consciousness in more detail.

Attention

In this section, we will explore the four main functions of attention—signal detection and vigilance, search, selective attention, and divided attention—as well as theories to explain them (see also Table 4.1 ■). We also will look at a number of neuroscientific

Table 4.1 Four Main Functions of Attention

Function	Description	Example
Signal detection and vigilance	We try to detect the appearance of a particular stimulus.	• In a research submarine, we may watch for unusual sonar blips; • on a dark street, we may try to detect unwelcome sights or sounds; • following an earthquake, we may be wary of the smell of leaking gas or of smoke.
Search	We engage in an active search for particular stimuli.	• If we detect smoke (as a result of our vigilance), we may engage in an active search for the source of the smoke. • We may search for missing keys, sunglasses, and other items.
Selective attention	We choose to attend to some stimuli and ignore others. Focusing our attention helps us execute other cognitive processes, such as verbal comprehension or problem solving.	• We may pay attention to reading a textbook or to listening to a lecture while ignoring such stimuli as a nearby radio or latecomers to the lecture.
Divided attention	We engage in more than one task at a time, and we shift our attentional resources to allocate them as needed.	• Experienced drivers easily can talk while driving under most circumstances, but if another vehicle is swerving toward their cars, they quickly switch all their attention toward driving (and away from talking).

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studies and explanatory models. Last, we will turn our attention to situations and conditions when our attention fails us.

Attending to Signals over the Short and Long Terms

Have you ever spent a hot summer day at an overcrowded beach? People are lying side by side on the sand, lined up like sardines in a tin. And although a trip to the water might bring some relief from the heat, it does not provide any relief from the crowding on the beach—a throng of people are standing in the water with little space to move unless you move out considerably further into the water. The lifeguards on duty must constantly monitor the crowds in the water to detect anything that seems unusual and act fast in case of an emergency. In the short term, they quickly have to detect a crucial stimulus among the mass of stimuli on the beach (*signal detection*), for example, making sure no one is drowning; in the long term, however, they also have to maintain their attention over a long period (*vigilance*) to ensure that nothing is amiss during their entire working period. What factors contribute to their ability to detect events that might be emergencies? How do they search the beaches and shorelines to detect important stimuli? Understanding this function of attention has immediate practical importance. Occupations requiring vigilance include those involving communications, warning systems and quality control, as well as the work of police detectives and physicians. They require sustained attention over time (Nobre & Koull, 2010). Also, research psychologists must search out from among a diverse array of items those that are more important. In each of these settings, people must remain alert to detect the appearance of a stimulus. But in each setting, there are also distracters, as well as prolonged periods during which the stimulus is absent. In the following sections, we will first explore how people detect a target stimulus out of a wealth of stimuli (i.e., how they detect signals). Once we understand how people discriminate between target signals and distracters, we will turn to the maintenance of attention over a prolonged period of time (vigilance) to detect important stimuli.

Signal Detection: Finding Important Stimuli in a Crowd

Signal-detection theory (SDT) is a framework to explain how people pick out the important stimuli embedded in a wealth of irrelevant, distracting stimuli. SDT often is used to measure sensitivity to a target's presence. When we try to detect a target stimulus (**signal**), there are four possible outcomes (Table 4.2 ■). Let's stay with our example of the lifeguard. First, in *hits* (also called "true positives"), the lifeguard correctly identifies the presence of a target (i.e., somebody drowning). Second, in *false alarms* (also called "false positives"), he or she incorrectly identifies the presence of a target that is actually

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(a) (b) (c)

Signal Detection, Vigilance, and Search in Everyday Life. (a) Signal detection. Physicians learn techniques to read x-rays to enable them to maximize "hits" and "correct rejections" and to minimize "false alarms" and "misses." (b) Vigilance. For air traffic controllers, vigilance is a matter of life and death. (c) Search. These trained police dogs are actively seeking out a target, such as bombs or drugs.

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Table 4.2 **Signal-Detection Matrix Used in Signal-Detection Theory**

Signal-detection theory was one of the first theories to suggest an interaction between the physical sensation of a stimulus and cognitive processes such as decision making. Think about the work of airport screeners. They need to be capable of perceiving objects such as a box cutter in hand-carried luggage.

Signal	Detect a Signal	Do Not Detect a Signal
Present	Hit: The screener recognizes a box cutter in the luggage.	Miss: The screener fails to see the box cutter in the luggage.
Absent	False alarm: The screener thinks there is a box cutter in the luggage when there is none.	Correct rejection: The screener recognizes that there is no box cutter in the luggage, and indeed, there is none.

absent (i.e., the lifeguard thinks somebody is drowning who actually isn't). Third, in *misses* (also called "false negatives"), the lifeguard fails to observe the presence of a target (i.e., the lifeguard does not see the drowning person). Fourth, in *correct rejections* (also called "true negatives"), the lifeguard correctly identifies the absence of a target (i.e., nobody is drowning, and he or she knows that nobody is in trouble).

Usually, the presence of a target is difficult to detect. Thus, we make detection judgments based on inconclusive information with some criteria for target detections. The number of hits is influenced by where you place your criteria for considering something a hit. In other words, how willing are you to make false alarms? For example, in the case of the lifeguard, the consequences of a miss are so grave that the lifeguard lowers the criteria for considering something as a hit. In this way, he or she increases the number of false alarms to boost hits (correct detections).

This trade-off often occurs with medical diagnoses as well. For example, it might occur with highly sensitive screening tests in which positive results lead to further tests. Thus, overall sensitivity to targets must reflect a flexible criterion for declaring the detection of a signal. If the criterion for detection is too high, then the doctor will miss illnesses (misses). If the criterion is too low, the doctor will falsely detect illnesses that do not exist (false alarms). Sensitivity is measured in terms of hits minus false alarms.

SDT can be discussed in the context of attention, perception, or memory:

- attention—paying enough attention to perceive objects that are there
- perception—perceiving faint signals that may or may not be beyond your perceptual range (such as a high-pitched tone)
- memory—indicating whether you have or have not been exposed to a stimulus before, such as whether the word *champagne* appeared on a list that was to be memorized

Disturbingly, on September 11, 2001, when terrorists crashed two airliners into the Twin Towers in New York City, the hijackers had been screened at airports as they prepared to board their flights. Several of them were pulled aside because they set off metal detectors. After further screening, they were allowed onto their planes anyway, even though they were carrying box cutters. The results of what constituted a "miss" for the screeners were disastrous. As a result of this fiasco, the rules for screening were tightened considerably. But the new rules created many false alarms. Babies, grandmothers, and other relatively low-risk passengers started to get second and sometimes even third screenings. So the rules were modified to profile passengers by computer. For example, those who bought one-way tickets or changed their flight plans at the last moment became more likely to be subjected to extra screening. This procedure, in turn, has inconvenienced those travelers who need to change their travel plans frequently, such as business travelers. The system for screening passengers is constantly evolving to minimize both misses and false alarms.

Vigilance: Waiting to Detect a Signal

When you have to pay attention to detect a stimulus that can occur at any time over a long period of time, you need to be vigilant.

What Is Vigilance? **Vigilance** refers to a person's ability to attend to a field of stimulation over a prolonged period, during which the person seeks to detect the appearance of a particular target stimulus of interest. An individual who watchfully waits to detect a signal stimulus that may appear at an unknown time is being vigilant. Typically, vigilance is needed in settings in which a given stimulus occurs only rarely but requires immediate attention as soon as it does occur. Military officers watching for a sneak attack are engaged in a high-stakes vigilance task.

In an early study, participants watched a visual display that looked like the face of a clock (Mackworth, 1948). A clock hand moved in continuous steps except that sometimes it would take a double step, which needed to be detected by the participants. Participants' performance began to deteriorate substantially after just half an hour of observation (see MacLean et al., 2009, for a more recent study). To relate these findings to SDT, over time, it appears that participants become less willing to risk reporting false alarms. They err instead by failing to report the presence of the signal stimulus when they are not sure they detect it, showing higher rates of misses. Training can help to increase vigilance, but to counteract fatigue, nothing but taking a break really helps much (Fisk & Schneider, 1981).

In vigilance tasks, expectations regarding stimulus location strongly affect response efficiency (LaBerge, Carter, & Brown, 1992; Motter, 1999). Thus, a busy lifeguard or air-traffic controller may respond quickly to a signal within a narrow radius of where a signal is expected to appear. But signals appearing outside the concentrated range of vigilant attention may not be detected as quickly or as accurately. However, the abrupt onset of a stimulus (i.e., the sudden appearance of a stimulus) captures our attention (Yantis, 1993). Thus, we seem to be predisposed to notice the sudden appearance of stimuli in our visual field. We might speculate about the adaptive advantage this feature of attention may have offered to our ancestral hunter-gatherer forebears. They presumably needed to avoid predators and had to catch prey.

When you attend a long lecture, you will try to keep your vigilance up as long as possible to follow the lecture. Also, if you have ever walked at night through a dark, deserted park or section of the city, you may have been vigilant with respect to any noises that indicate the presence of someone else close by. Vigilance is extremely important during scans at airports in detecting abandoned bags or suspect items that may pose a security risk. Medical workers interpreting results from magnetic resonance imaging (MRI) scans or X-rays need to be vigilant as well, watching for any abnormalities in the results they are interpreting, even if they are small. The costs of failure of vigilance, in the twenty-first century, can be great loss of life as well as of property.

Neuroscience and Vigilance Both the amygdala and thalamus are involved in vigilance. The amygdala particularly plays a pivotal role in the recognition of emotional stimuli (for example when someone is confronted with a threatening stimulus; Phelps, 2004, 2006; van Marle et al., 2009). An electroencephalogram (EEG) will show less low-frequency activity and bigger event-related potentials (ERPs) the more vigilant a person is (Llinas & Steriade, 2006; Oken, Salinsky, & Elsas, 2006).

Search: Actively Looking

Have you ever picked up your parents or friends at a crowded airport and tried to locate them among the masses of people streaming out of the terminals? Search involves using our attentional resources to actively and often skillfully seek out a target (Cisler, Bacon,

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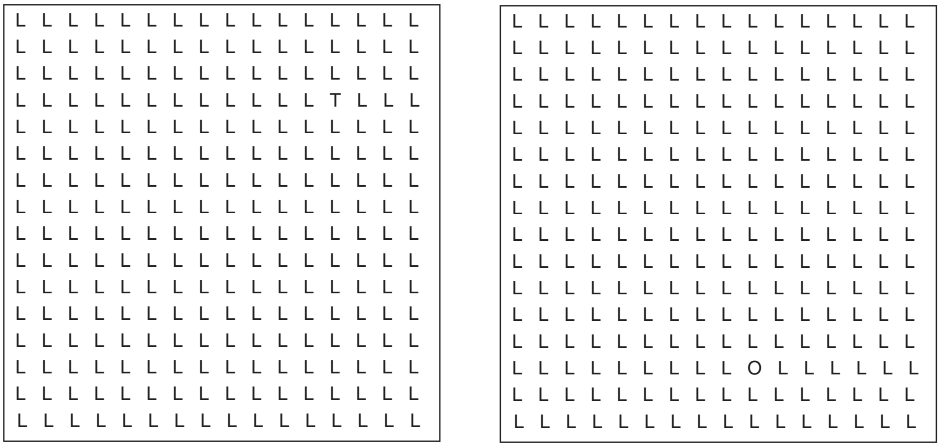
& Williams, 2007; Posner & DiGirolamo, 1998). Specifically, **search** refers to a scan of the environment for particular features—actively looking for something when you are not sure where it will appear (Mangun, 2012). As with vigilance, when we are searching for something, we may respond by making false alarms. Search is made more difficult by **distracters**, nontarget stimuli that divert our attention away from the target stimulus. In the case of search, false alarms usually arise when we encounter such distracters while searching for the target stimulus. For instance, consider searching for a product in the grocery store. We often see several distracting items that look something like the item we hope to find. Package designers take advantage of the effectiveness of distracters when creating packaging for products. For example, if a container looks similar to a box of Cheerios™, you may pick it up without realizing that it's really Tasteeos®.

There are two different kinds of searches—feature searches and conjunction searches. In a **feature search**, we look for just one feature (e.g., color, shape, or size) that makes our search object different from all others (Treisman, 1993; Weidner & Mueller, 2009). Therefore, the number of distracters does not really play a role in slowing us down. In a **conjunction search**, we have to combine two or more features to find the stimulus we're looking for. Because in conjunction searches we look for a combination of features, these searches are more difficult than feature searches that look for just one feature. Look at Figure 4.2(b) ■ and try to find the *O*. This search should be relatively easy because you are searching for a distinct shape (feature search). Then look at Figure 4.2(a) ■ and search for the *T*. This is an example of a conjunction search because both the *T*s and the *L*s are made up of a horizontal and a vertical line and you are looking for a particular combination of those lines to make up the L. This search should be more difficult and time-consuming than finding the *O*.

The number of targets and distracters affects the difficulty of conjunction searches. Investigators often manipulate *display size* in their studies (the number of items in a given visual array) and then observe which factors affect the search. The dorsolateral prefrontal cortex as well as both frontal eye fields and the posterior parietal cortex play a role in conjunction searches (but not in feature searches; Kalla et al., 2009).

In the following section, we explore two theories that try to explain search processes. These theories have developed in a dialectical way as responses to each other: feature-integration theory and similarity theory.



(a) **(b)**

■ **Figure 4.2 Display Size.** Compare the relative difficulty in finding the T and the O in panels (a) and (b), respectively. The display size affects your ease of performing the task.

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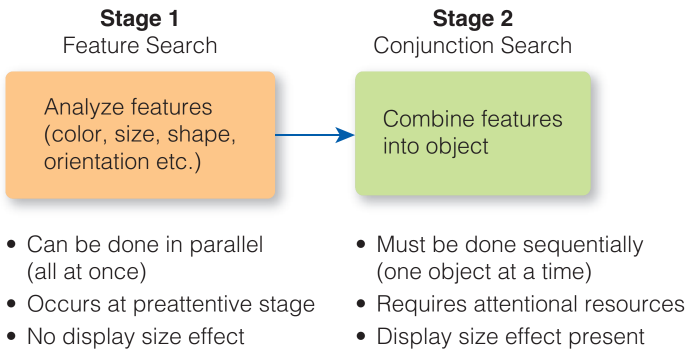

Stage 1
Feature Search
Analyze features (color, size, shape, orientation etc.)
Stage 2
Conjunction Search
Combine features into object
• Can be done in parallel (all at once)
• Occurs at preattentive stage
• No display size effect
• Must be done sequentially (one object at a time)
• Requires attentional resources
• Display size effect present

■ **Figure 4.3 Treisman's Feature Integration Theory.** According to Treisman (1986), we first analyze individual features of an object and subsequently integrate those features into the object.

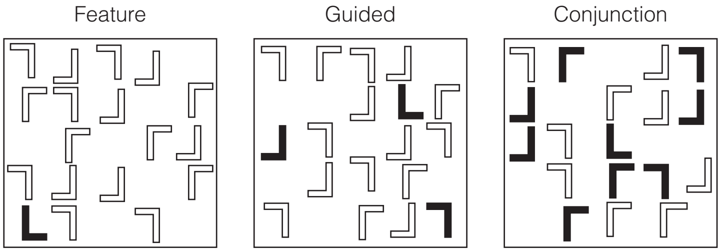
Feature-Integration Theory

Feature-integration theory explains why it is relatively easy to conduct feature searches and relatively difficult to conduct conjunction searches. Anne Treisman (1986) developed a model of how our minds conduct visual searches. She suggested that two stages are involved when we perceive objects. In the first stage, we perceive features of objects, including color and size (see Figure 4.3 ■). This process is automatic and does not need our conscious attention. This first stage occurs in feature searches. We can recognize a stimulus immediately and do not need additional time for cognitive processing. The second stage of object perception involves our connecting two or more features with some sort of "mental glue." This stage requires our conscious attention. Think back to how you had to combine two lines to form a *T* in the search panel in Figure 4.2(a). Or think of a search for a blue letter *T* during which you not only have to look for the color blue but also the letter *T* in the correct color. Because we have to combine the features we are searching for one by one, there are effects of display size (i.e., it takes longer to search for a given stimulus if there is a larger number of items in the search panel).

Treisman's model has received some neuropsychological support. For example, Nobel laureates David Hubel and Torsten Wiesel (1979) identified specific neural feature detectors. These are cortical neurons that respond differentially to visual stimuli of particular orientations (e.g., vertical, horizontal, or diagonal), corresponding to features we may use during feature searches. More recent research has suggested, however, that the brain does not necessarily increase the activity of neurons that respond to the target stimuli. Instead, a better strategy is to activate neurons that can distinguish between the target and distracters while ignoring those neurons that respond best only to the target directly (Navalpakkam & Itti, 2007; Pouget & Bavelier, 2007).

Similarity Theory

Not everyone agrees with Treisman's model, however. According to *similarity theory*, the more similar target and distracters are, the more difficult it is to find the target (Duncan & Humphreys, 1992; Watson et al., 2007). Furthermore, the difficulty of search tasks depends on how different distracters are from each other. But it does not depend on the number of features to be integrated. For instance, it is easier to read long strings of text written in lowercase letters than text written in capital letters because capital letters tend to be more similar to one another in appearance. Lowercase letters, in contrast, have more distinguishing features.



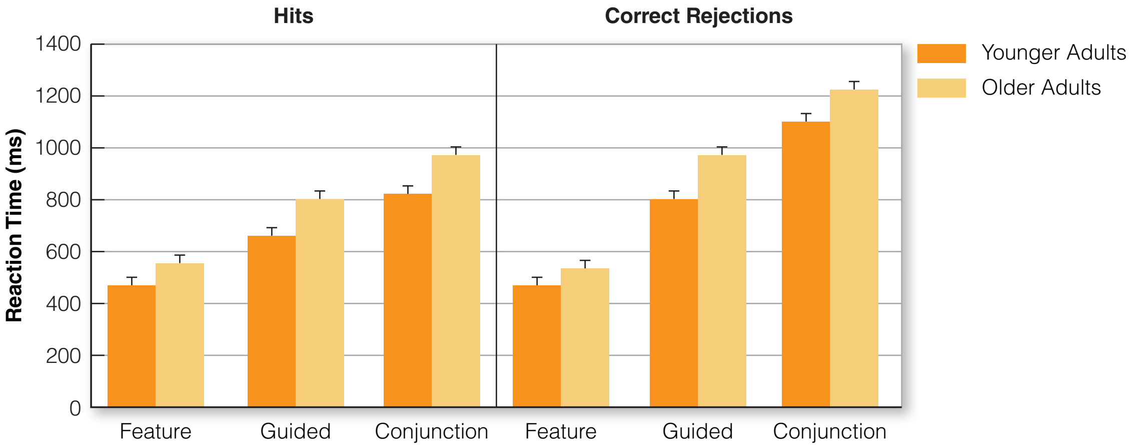
■ **Figure 4.4** **Search Tasks in an Experiment.** Here are examples for feature search, guided search, and conjunction search. In all three cases, participants were instructed to look for the upright black *L*.

Source: Madden, D. J., Turkington, T. G., Provenzale, J. M., Denny, L. L., Langley, L. K., Hawk, T. C., et al. (2002). Aging and attentional guidance during visual search: Functional neuroanatomy by positron emission tomography. *Psychology and Aging*, 17(1), 24–43.

Neuroscience: Aging and Visual Search

An interesting study investigated the effect of aging on visual search capabilities (Madden, 2007; Madden et al., 2002). The researchers had two groups of participants—one group in their 20s and one group between 60 and 77 years of age—conduct a variety of visual searches of various difficulties for a black upright *L*: (1) a feature search in which participants had to find the black upright *L* between white, partly rotated *L*s; (2) a guided search in which the target had to be found in between white *L*s as well as three black *L*s of various rotation; and (3) a conjunction search in which the black *L* had to be found in between a variety of rotated *L*s that were either black or white (Figure 4.4 ■).

Younger adults' searches were more accurate and faster than the searches of the older adults (see Figure 4.5 ■). Also, participants were slower by approximately 300 milliseconds when doing guided searches as compared with feature searches. Older adults' cortical volume was lower than that of the younger adults (see also Mueller-Oehring et al., 2013), which is consistent with an approximate decline in volume of 2% per decade. The most difficult search (conjunction search) led to activation in the dorsal and ventral visual pathways as well as the prefrontal cortex in both young and older adults. Although there was less activation in the right occipital cortex in older adults, the activation was about the same in both age-groups in the prefrontal and superior parietal



■ **Figure 4.5** **Reaction Times in Madden's Experiment on Aging and Visual Search.** The reaction times for correct answers (hits: participants correctly gave a yes response; correct rejection: participants correctly gave a no response) were longer for older adults compared with younger adults.

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regions. The more difficult a search task was, the more the occipitotemporal cortex was activated in younger adults but not in older adults. The older adults seem to have this brain region activated at a higher level even during easier search tasks, apparently trying to compensate for the age-related decline. They, however, did not recruit other brain regions outside the visual pathways to compensate for this age-related decline.

Selective Attention

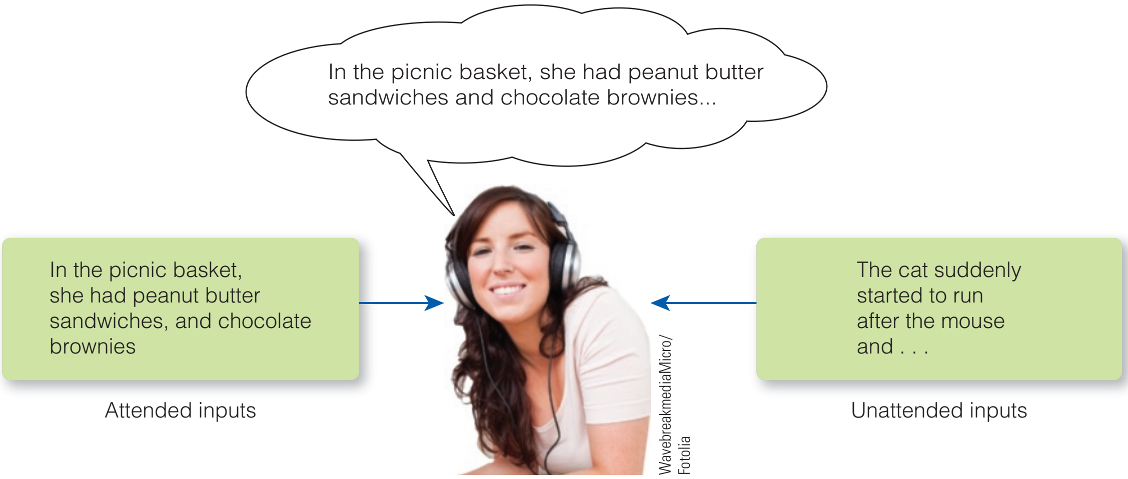
We explored the first two functions of attention—signal detection and search. Now, let's examine another function of attention—**selective attention**.

What Is Selective Attention?

Suppose you are at a dinner party. It is just your luck that you are sitting next to a salesman. He sells 110 brands of vacuum cleaners. He describes to you in excruciating detail the relative merits of each brand. As you are listening to this blatherer, who happens to be on your right, you become aware of the conversation of the two diners sitting on your left. Their exchange is much more interesting. It is juicy information about one of your acquaintances. You find yourself trying to keep up the semblance of a conversation with the blabbermouth on your right, but you are also tuning in to the dialogue on your left.

Colin Cherry (1953; see also Bee & Micheyl, 2008) referred to this phenomenon as the **cocktail party problem**, the process of tracking one conversation while distracted by other conversations. He observed that cocktail parties are often settings in which selective attention is salient. Cherry did not actually hang out at numerous cocktail parties to study conversations. He studied selective attention in a more carefully controlled experimental setting. He devised a task known as shadowing. In *shadowing*, you listen to two different messages. Cherry presented a separate message to each ear, known as **dichotic presentation**. Figure 4.6 ■ illustrates how these listening tasks might be presented. You are required to repeat back only one of the messages as soon as possible after you hear it. In other words, you are to follow one message (think of a detective "shadowing" a suspect) but ignore the other.

Cherry's participants successfully shadowed distinct messages in dichotic-listening tasks, although such shadowing required a significant amount of concentration. The participants were also able to notice physical, sensory changes in the unattended


In the picnic basket, she had peanut butter sandwiches and chocolate brownies...
In the picnic basket, she had peanut butter sandwiches, and chocolate brownies
Attended inputs
The cat suddenly started to run after the mouse and . . .
Unattended inputs

WavebreakmediaMicro/Fotolia

■ **Figure 4.6 Dichotic Presentation.** In dichotic presentation, each ear is presented a separate message. The shadowed ear is the one that is presented with the target message.

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message—for example, when the message was changed to a tone or the voice changed from a male to a female speaker. They did not, however, notice semantic changes in the unattended message. They failed to notice even when the unattended message shifted from English to German or was played backward. Conversely, about one-third of people, when their name is presented during these situations, will switch their attention to their name. Some researchers have noted that those who hear their name in the unattended message tend to have limited working-memory capacity. As a result, they are easily distracted (Conway, Cowan, & Bunting, 2001). Infants listening to two messages also will shift their attention to the one in which their name is said (Newman, 2005).

So what helps us to attend only to the message of the target speaker to whom we wish to listen?

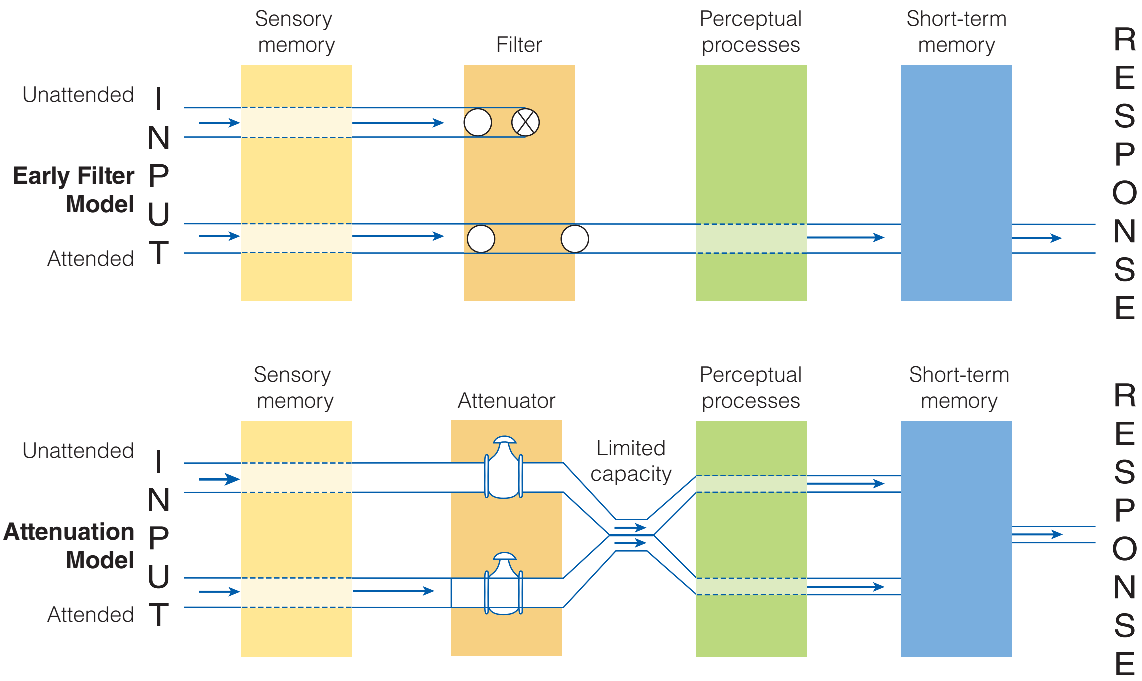
1. distinctive sensory characteristics of the target's speech (e.g., high versus low pitch, pacing, and rhythmicity)
2. sound intensity (loudness)
3. location of the sound source (Brungard & Simpson, 2007)

Attending to the sensory properties of the target speaker's voice has its advantages because you do not have to deal with the content of unattended messages. Clearly, the sound intensity of the target also helps. In addition, you probably turn one ear toward and the other ear away from the target speaker. Note that this method offers no greater total sound intensity but accounts for a difference in volume because one ear is closer to the speaker and one is farther away. Recent psychophysical studies have found, however, that factors such as how harmonious and rhythmic the target sounds may be even more important than other cues (Darwin, 2008; Muente et al., 2010).

Theories of Selective Attention

In the following section, we will discuss several theories of selective attention (one of the four main functions of attention). Note how dialectical processes influenced the development of subsequent theories. The theories described here belong to the group of filter and bottleneck theories. A filter blocks some of the information going through and thereby selects only a part of the total of information to pass through to the next stage. A bottleneck slows down information passing through. The models differ in two ways: (1) whether or not they have a distinct filter for incoming information, and (2) if the filter occurs early or late in the processing of information.

Early Filter Model According to one of the earliest theories of attention, we filter information right after we notice it at the sensory level (Broadbent, 1958; Figure 4.7 ■). That is, all the incoming information is being perceived and stored in sensory memory. Sensory memory only stores the information for a split second and then forwards it to a filter that allows only one message to move forward to be processed in more detail. That message is distinguished by characteristics such as loudness, pitch, or accent. The stimuli that are filtered out at the sensory level may never reach the level of perception. Except for the one message that will be further processed, all other information is being processed. Short-term memory then enables us to respond to the message and to store necessary information for future use in long-term memory. Donald Broadbent's theory was supported by Colin Cherry's findings that sensory information sometimes may be noticed by an unattended ear if it does not have to be processed elaborately (e.g., you may notice that the voice in your unattended ear switches to a tone). But information requiring higher perceptual processes is not noticed if not attended to (e.g., you would likely not notice that the language in your unattended ear switches from English to German).



■ **Figure 4.7 Broadbent and Treisman's Models of Attention.** Various mechanisms have been proposed suggesting a means by which incoming sensory information passes through the attentional system to reach high-level perceptual processes. In Broadbent's model, a filter completely blocks out unattended information, and only the attended message is forwarded to be processed. In Treisman's model, an attenuator weakens the unattended message. It is still being forwarded in its weakened form, however, so that information of great significance can be picked up by the listener and subsequently can be processed.

Selective Filter Model Not long after Broadbent's theory was proposed, evidence began to suggest that his model must be wrong (e.g., Gray & Wedderburn, 1960). Moray (1959) found that even when participants ignore most other high-level (e.g., semantic) aspects of an unattended message, they frequently still recognize their names in an unattended ear (Wood & Cowan, 1995). Moray suggested that the reason for this effect is that messages that are of high importance to a person may break through the filter of selective attention (e.g., Koivisto & Revonsuo, 2007; Marsh et al., 2007). But other messages may not. To modify Broadbent's metaphor, one could say that, according to Moray, the filter blocks out most information at the sensory level. But some personally important messages are so powerful that they burst through the filtering mechanism.

Attenuation Model To explore why some unattended messages pass through the filter, Anne Treisman conducted some experiments. She had participants shadowing coherent messages, and at some point, she switched the remainder of the coherent message from the attended to the unattended ear. Participants picked up the first few words of the message they had been shadowing in the unattended ear (Treisman, 1960), so they must have been somehow processing the content of the unattended message. Moreover, if the unattended message was identical to the attended one, all participants noticed it. They noticed even if one of the messages was slightly out of temporal synchronization with the other (Treisman, 1964a, 1964b). Treisman also observed that some fluently bilingual participants noticed the identity of messages if the unattended message was a translated version of the attended one.

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Moray's modification of Broadbent's filtering mechanism was clearly not sufficient to explain Treisman's modification (1960, 1964a, 1964b) findings. Her findings suggested that at least some information about unattended signals is being analyzed. Treisman proposed a theory of selective attention that involves an attenuating mechanism (Figure 4.7). Instead of blocking out stimuli, the filter (attenuator) merely weakens (attenuates) the strength of all stimuli other than the target stimulus. So when the stimuli reach us, we analyze them at a low level for target properties such as loudness and pitch. You may listen for the voice of the person you are talking to in a noisy bar, for example. If the stimuli possess those target properties, we pass the signal on to the next stage; if they do not possess those target properties, we pass on a weakened version of the stimulus. In a next step, we perceptually analyze the meaning of the stimuli and their relevance to us. If a message from the unattended ear contains some information that is important to us (e.g., our name), it will be picked up, even though the signal has been weakened by the attenuator. That is, although the attenuator weakens some streams of information to make it easier for us to process the attended message, we still receive that information as a weakened signal and thus can pick up information that is of relevance. Because the unattended messages are weaker, only parts will be picked up that are of significance, whereas the rest will go unnoticed.

INVESTIGATING COGNITIVE PSYCHOLOGY

Attenuation Model

Get two friends to help you with this experiment. Ask one friend to read something softly into your other friend's ear (it can be anything—a joke, a greeting card, or a cognitive psychology textbook) and have your other friend try to "shadow" what the other friend is saying. (Shadowing is repeating all the words that another person is saying.) In your friend's other ear, say "animal" very softly. Later, ask your friend what you said. Is your friend able to identify what you said? Probably not. Try this again, but this time say your friend's name. Your friend most likely will be able to recall that you said his or her name. This finding demonstrates Treisman's attenuation model.

Late-Filter Model Deutsch and Deutsch (1963; Norman, 1968) developed a model in which the location of the filter is even later in the process (Figure 4.8 ■). They suggested that stimuli are filtered out only after they have been analyzed for both their physical properties and their meaning. This later filtering would allow people to recognize information entering the unattended ear. For example, they might recognize the sound of their own names or a translation of attended input (for bilinguals). Proponents of both the early and the late-filtering mechanisms propose that an attentional bottleneck exists through which only a single source of information can pass. The two models differ only in terms of where they hypothesize the bottleneck to be positioned.

A Synthesis of Early Filter and Late-Filter Models Both early and late selection theories have data to support them. So what is a researcher to do? In 1967, Ulric Neisser synthesized the early filter and the late-filter models and proposed that two processes govern attention:

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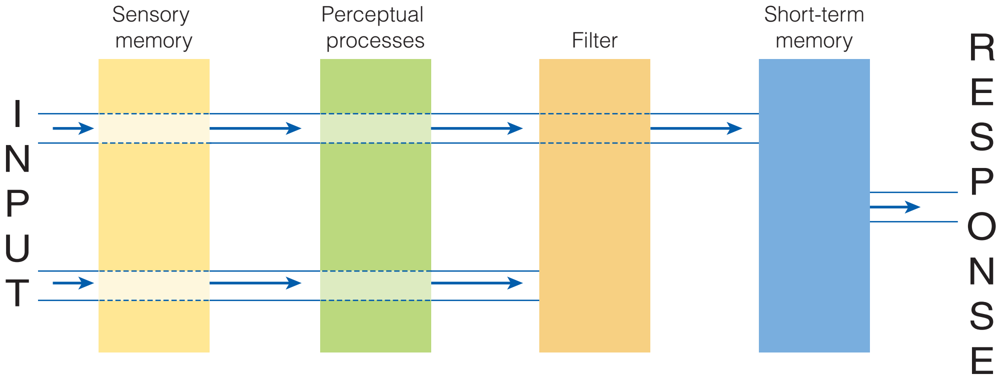

Figure 4.8 Deutsch and Deutsch's Late-Filter Model. According to some cognitive psychologists, the attentional filtering mechanisms follow, rather than precede, preliminary perceptual processes.

- *Preattentive processes:* These automatic processes are rapid and occur in parallel. They can be used to notice only physical sensory characteristics of the unattended message. But they do not discern meaning or relationships.
- *Attentive, controlled processes:* These processes occur later. They are executed serially and consume time and attentional resources, such as working memory. Information is processed in much more detail here.

A two-step model could account for Cherry's, Moray's, and Treisman's data. The model also nicely incorporates aspects of Treisman's signal-attenuation theory and of her subsequent feature-integration theory. Remember how Treisman suggested that we can use two different processes during searches: feature detection and feature integration? The feature-detection process may be linked to preattentive, automatic processing. The feature-integration process may be linked to attentive, conscious processing. Unfortunately, however, the two-step model does not do a good job of explaining the continuum of processes from fully automatic ones to fully controlled ones. Recall, for example, that fully controlled processes appear to be at least partially automatized (Spelke, Hirst, & Neisser, 1976). How does the two-process model explain the automatization of processes in divided-attention phenomena? For example, how can one read for comprehension while writing dictated, categorized words? We will discuss this in the section on divided attention.

Neuroscience and Selective Attention

As early as in the 1970s, researchers employed ERPs to study attention. A groundbreaking study was conducted by Hillyard et al. (1973), when they exposed their participants to two streams of tones, one in each ear (the streams differed in pitch). The participants had to detect occasionally occurring target stimuli. When the target stimuli occurred in the attended ear, the first negative component of the ERP was larger than when the target occurred in the unattended ear. N1 is a negative wave that appears about 90 milliseconds after the onset of the target stimulus. The researchers hypothesized that the N1 wave was a result of the enhancement of the target stimulus. At the same time, the other stimuli were suppressed. This result is consistent with filter theories. Later studies (Woldorff & Hillyard, 1991) found an even earlier reaction to the target stimulus in the form of a positive wave that occurs about 20–50 milliseconds after the onset of a target. The wave originates in the Heschl's gyri, which are located in the auditory cortex (Woldorff et al., 1993). Twenty-first-century studies still use these methods to explore topics as diverse as the influence of mothers' socioeconomic status on children's selective attention

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in the lab of **JOHN F. KIHLSTROM**

Hypnosis and Posthypnotic Amnesia

Hypnosis is a special state of consciousness in which subjects may see things that aren't there, fail to see things that are there, and respond to posthypnotic suggestions without knowing what they are doing or why (Kihlstrom, 2007, 2008). Afterward, they may be unable to remember the things they did while they were hypnotized—a phenomenon known as *posthypnotic amnesia*, which has been a major focus of my work.

Before testing for posthypnotic amnesia, however, we have to find the right subjects. Unfortunately, there is no way to predict in advance who can experience hypnosis and who cannot. The only way to find out is to try hypnosis and see whether it works. For this purpose, we rely on a set of standardized scales of hypnotic susceptibility. These are performance-based tests structured much like tests of intelligence. Each scale begins with an induction of hypnosis, followed by a series of suggestions for various hypnotic experiences. Response to each suggestion is evaluated according to objective behavioral criteria, yielding a total score representing the person's ability to experience hypnosis.

Courtesy of the author

John F. Kihlstrom

From this point on, however, our experiments on cognition look just like anyone else's—except that our subjects are hypnotized. In one study using a traditional verbal-learning paradigm (Kihlstrom, 1980), the subjects memorized a list of 15 familiar words, such as *girl* or *chair*, and then received a suggestion that "you will not be able to remember that you learned any words while you were hypnotized . . . until I say to you, 'Now you can remember everything.'" After coming out of hypnosis, highly hypnotizable subjects remembered virtually none of the study list, whereas insusceptible subjects, who had gone through the same procedures, remembered it almost perfectly. This finding shows that the occurrence of posthypnotic amnesia is highly correlated with hypnotizability.

Following hypnosis, subjects completed a word association test, in which they were asked to report the first word that came to mind. Some of the cues were words such as *boy* or *chair*, which were likely to elicit items from the study list. Others were equally likely to elicit control words that had not been studied. Despite their inability to remember the words they had just studied, the hypnotizable, amnesic subjects produced items from the study list at the same rate as the insusceptible, nonamnesic subjects. This finding shows that posthypnotic amnesia is a disruption of episodic, but not semantic, memory. Even more important, the subjects showed semantic priming, responding with items from the study list *more* often, compared with other items that they had *not* previously studied. The magnitude of the priming effect was the same in the hypnotizable, amnesic subjects as it was in the insusceptible, nonamnesic subjects. In other words, posthypnotic amnesia entails a dissociation between explicit and implicit expressions of episodic memory (Schacter, 1989).

Although explicit and implicit memory are dissociated in other forms of amnesia, the dissociation observed in posthypnotic amnesia has some features that make it special. Most studies of implicit memory in neurologically intact subjects employ highly degraded encoding conditions, such as shallow processing, to impair explicit memory. But in our experiments, the subjects deliberately memorized the list to a strict criterion of learning before the amnesia suggestion was given, and they remembered the list perfectly well after the amnesia suggestion was canceled. Thus, implicit memory can be dissociated from explicit memory even under optimal, deep processing conditions.

More important, most studies of implicit memory in amnesia focus on repetition priming, which can be mediated by a perception-based representation of the prime. Accordingly, some of the most popular theories of implicit memory focus on perceptual representation systems in the brain. But in our original study, the priming was semantic in nature and must have been mediated by a meaning-based representation of the prime. In this way, studies of hypnosis remind us that a comprehensive theory of implicit memory is going to have to go beyond repetition priming and beyond perceptual representation systems.

Other research subsequently showed that posthypnotic amnesia spared repetition priming as well as semantic priming. More important, studies using Jacoby's "process-dissociation procedure" confirmed that the priming effects were mediated by automatic rather than controlled processing. Studies of posthypnotic amnesia, and other phenomena of hypnosis, promise to give us insights into the nature of unconscious mental life. Also, by enabling experimenters to control conscious perception and memory, hypnosis may be of use in brain-imaging research seeking to uncover the neural substrates of conscious and unconscious cognition.

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(Stevens, Lauinger, & Neville, 2009). They have found that children of mothers with lower levels of education show reduced effects of selective attention on neural processing.

Similar effects also have been found for visual attention. If a target stimulus appears in an attended region of the visual field, the occipital P1 (a wave of positive polarity) is larger than when the target appears in an unattended region (Eason, Harter, & White, 1969; Van Voorhis & Hillyard, 1977). The P1 effect also occurs when participants' attention is drawn to a particular location by a sensory cue, and the target subsequently appears in just that location. If the interval between the appearance of the cue and the target is small, the P1 wave is enlarged and the reaction time is faster than for targets that appear with a significant delay after the cue. In fact, a delay between cue and target can even lead to a delay in reaction time and decreased size of P1 wave (Hopfinger & Mangun, 1998, 2001).

Divided Attention

Have you ever been driving with a friend and the two of you were engaged in an exciting conversation? Or have you made dinner while on the phone with a friend? Anytime you are engaged in two or more tasks at the same time, your attention is divided between those tasks.

Investigating Divided Attention in the Lab

Early work in the area of **divided attention** had participants view a videotape in which the display of a basketball game was superimposed on the display of a hand-slapping game. Participants could successfully monitor one activity and ignore the other. They had great difficulty, however, in monitoring both activities at once, even if they viewed the basketball game with one eye and watched the hand-slapping game separately with the other eye (Neisser & Becklen, 1975).

Neisser and Becklen hypothesized that improvements in performance eventually would have occurred as a result of practice. They also hypothesized that the performance of multiple tasks was based on skill resulting from practice. They believed it not to be based on special cognitive mechanisms.

The following year, investigators used a dual-task paradigm to study divided attention during the simultaneous performance of two activities: reading short stories and writing down dictated words (Spelke, Hirst, & Neisser, 1976). The researchers would compare and contrast the response time (latency) and accuracy of performance in each of the three conditions. Of course, higher latencies mean slower responses. As expected, initial performance was poor for the two tasks when the tasks had to be performed at the same time. Spelke, Hirst, and Neisser, however, had their participants practice to perform these two tasks five days a week for many weeks (85 sessions in all). To the surprise of many, given enough practice, the participants' performance improved on both tasks. They showed improvements in their speed of reading and accuracy of reading comprehension, as measured by comprehension tests. They also showed increases in their recognition memory for words they had written during dictation. Eventually, participants' performance on both tasks reached the same levels that the participants previously had shown for each task alone.

When the dictated words were related in some way (e.g., they rhymed or formed a sentence), participants first did not notice the relationship. After repeated practice, however, the participants started to notice that the words were related to each other in various ways. They soon could perform both tasks at the same time without a loss in performance. Spelke suggested that these findings showed that controlled tasks

The dual task paradigm used in the study by Spelke, Hirst, & Neisser (1976). Participants had to read short stories and write down dictated words at the same time.

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can be automatized so that they consume fewer attentional resources. Furthermore, two discrete controlled tasks may be automatized to function together as a unit. The tasks do not, however, become fully automatic. For one thing, they continue to be intentional and conscious. For another, they involve relatively high levels of cognitive processing.

INVESTIGATING COGNITIVE PSYCHOLOGY

Dividing Your Attention

Repeatedly write your name on a piece of paper while you picture everything you can remember about the room in which you slept when you were 10 years old. While continuing to write your name and picturing your old bedroom, take a mental journey of awareness to notice your bodily sensations, starting from one of your big toes and proceeding up your leg, across your torso, to the opposite shoulder, and down your arm. What sensations do you feel—pressure from the ground, your shoes, or your clothing or even pain anywhere? Are you still managing to write your name while retrieving remembered images from memory and continuing to pay attention to your current sensations? Either task would have been easier done by itself than when done in parallel. Were you able to divide your attention successfully?

An entirely different approach to studying divided attention has focused on extremely simple tasks that require speedy responses. When people try to perform two overlapping speeded tasks (ones that large numbers of people cannot finish on time), the responses for one or both tasks are almost always slower (Pashler, 1994). When a second task begins soon after the first task has started, speed of performance usually suffers. This slowing is the psychological refractory period (PRP) effect, also called *attentional blink*. Findings from PRP studies indicate that people fairly easily process physical properties of incoming information while engaged in another speeded task (Miller, Ulrich, & Rolke, 2009; Pashler, 1994). However, when they need to engage in more elaborate processing such as choosing a response or retrieving information from memory, their speed will decline and one or both tasks will show the PRP effect.

How well people can divide their attention also has to do with their intelligence (Hunt & Lansman, 1982). For example, suppose that participants are asked to solve mathematical problems and simultaneously to listen for a tone and press a button as soon as they hear it. According to Hunt and Lansman, more intelligent people are better able to timeshare between two tasks and to perform both effectively. ■ Go to Lab 8, Attentional Blink, in CogLab to explore further.

Theories of Divided Attention

To understand our ability to divide our attention, researchers have developed *capacity models* of attention. These models help to explain how we can perform more than one attention-demanding task at a time. They posit that people have a fixed amount of attention that they can choose to allocate according to what the task requires. Two different kinds of models differ in terms of what the source of attention is (Kahneman, 1973, McDowd, 2007):

- One model suggests that one single pool of attentional resources can be divided freely.

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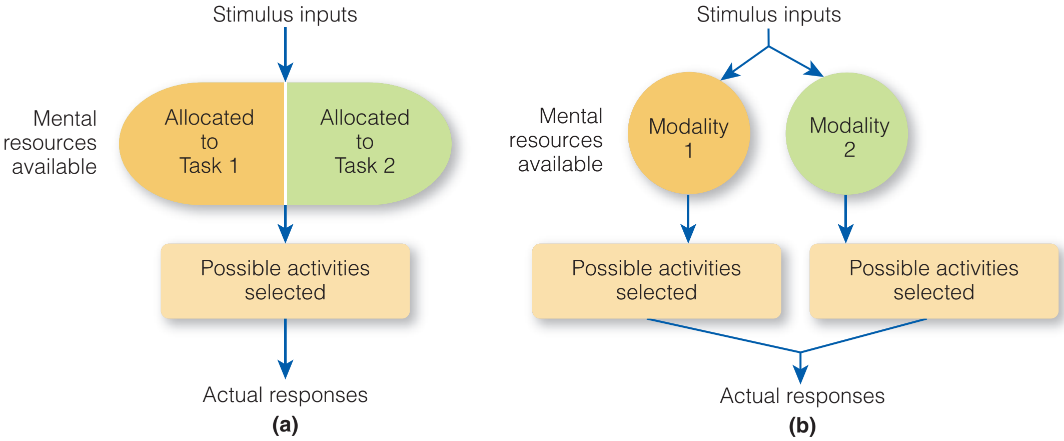
Stimulus inputs
Mental resources available
Allocated to Task 1
Allocated to Task 2
Possible activities selected
Actual responses
(a)
Stimulus inputs
Mental resources available
Modality 1
Modality 2
Possible activities selected
Possible activities selected
Actual responses
(b)

■ **Figure 4.9 Allocation of Attentional Resources.** Attentional resources may involve either a single pool or a multiplicity of modality-specific pools. Although the attentional resources theory has been criticized for its imprecision, it seems to complement filter theories in explaining some aspects of attention.

- Another model suggests multiple sources of attention are available, one for each modality (e.g., verbal or visual).

Figure 4.9 ■ shows examples of the two kinds of models. In Figure 4.9(a), the system has a single pool of resources that can be divided among multiple tasks (Kahneman, 1973). Figure 4.9(b) shows a model that has several pools of attention for different modalities (Navon & Gopher, 1979).

Single-pool models likely oversimplify what is going on. People are much better at dividing their attention when competing tasks are in different modalities. At least some attentional resources may be specific to the modality (e.g., verbal or visual) in which a task is presented. For example, most people can easily listen to music and concentrate on writing simultaneously. But it is harder to listen to the news station and concentrate on writing at the same time. The reason is that both are verbal tasks. The words from the news interfere with the words you are thinking about. Similarly, two visual tasks are more likely to interfere with each other than are a visual task coupled with an auditory one.

BELIEVE IT OR NOT

Are You Productive When You're Multitasking?

You're working on your term paper, you're texting with your best friend, and are having a little snack while listening to some music in the background. And you think you're productive? Researchers Paul Dux et al. (2006) have found that working on more than one task at the same time not only makes you slower but also increases your chances of making mistakes. Your reaction time goes down by up to one second when you do two things at once. Although this may not be so crucially important while you sit at your desk working, it can save or risk lives when you drive your car and text or make a call at the same time. Even your learning capabilities are impaired. A study by Foerde, Knowlton, and Poldrack (2006) found that the formation of declarative memory (which is essential for successful learning) is hampered even by little distractions, such as a sound in the background, because when we perform complex tasks, we keep a lot of information activated in our memory. The required concentration can easily be broken by external disturbances.

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These models regarding allocation of attentional resources have been criticized severely as overly broad and vague (e.g., Navon, 1984; S. Yantis, personal communication, December 1994). Indeed, they may not stand alone in explaining all aspects of attention, but they complement filter theories quite well.

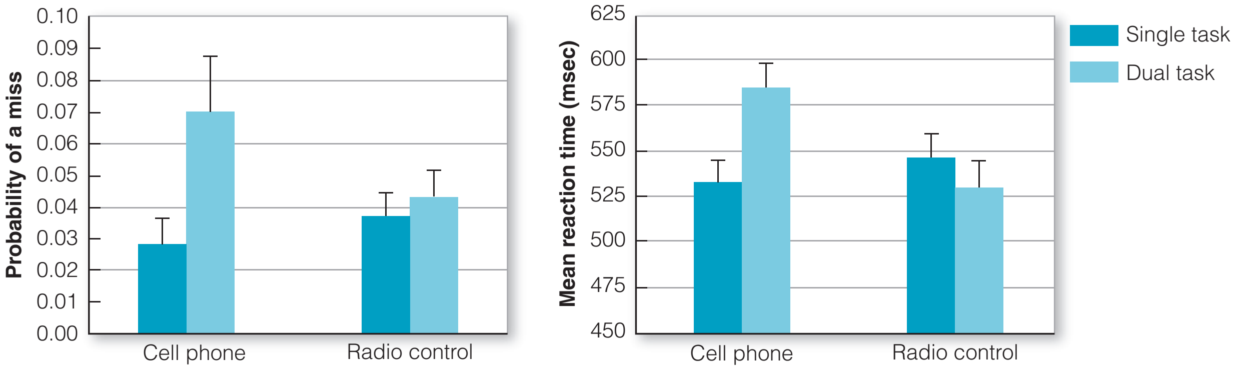
Additionally, for explaining search-related phenomena, theories specific to visual search (e.g., models proposing guided search [Cave & Wolfe, 1990; Wolfe, 2007] or similarity [Duncan & Humphreys, 1989]) seem to have stronger explanatory power than filter or resource theories.

Divided Attention in Everyday Life

Divided attention plays an important role in our lives. How often are you engaged in more than one task at a time? Consider driving a car, for example. You need to be constantly aware of threats to your safety. Suppose you fail to select one such threat, such as a car that runs a red light and is headed directly toward you as you enter an intersection. The result is that you may become an innocent victim of a horrible car accident. Moreover, if you are unsuccessful in dividing your attention, you may cause an accident. Most automobile accidents are caused by failures in divided attention.

Some intriguing studies are based on our own everyday experiences. One widely used paradigm simulates a driving situation (Strayer & Johnston, 2001; see also Fisher & Pollatsek, 2007). Researchers had participants perform a tracking task. The participants controlled a joystick, which moved a cursor on a computer screen. The participants needed to keep the cursor in position on a moving target. At various times, the target would flash either green or red. If the color was green, the participants were to ignore the signal. If the color was red, however, the participants were to push a simulated brake. The simulated brake was a button on the joystick. In one condition, participants only had to accomplish this one task. In another condition, participants were involved in a second task. This procedure created a dual-task situation. The participants either listened to a radio broadcast while doing the task or talked on a cell phone to an experimental confederate (a collaborator of the experimenter). Participants talked roughly half the time and also listened roughly half the time. Participants listened to different topics during the study to ensure that the results were not influenced by the topic of conversation.

As shown in Figure 4.10 ■, the probability of a miss in the face of the red signal increased substantially (and reaction times were slower) when participants had a cell



■ **Figure 4.10 Dual-Task Performance during Driving.** In the left panel, the dual-task performance significantly increased the probability of a miss in the cell phone condition but not in the radio-control condition. In the right panel, reaction time increased significantly for a dual task in the cell phone condition but not in the radio-control condition.

Source: Based on Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science*, 12, 463.

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phone conversation relative to when they were not talking on the phone. Listening to the radio, however, did not really impede their performance. Thus, use of cell phones appears to be substantially more risky than listening to the radio while driving (see also Charltona, 2009; Drews, Pasupathi, & Strayer, 2008). So when you are driving, you are better off not using your cell phone.

Additional studies have analyzed data from real-world incidents. A study of 2,700 crashes in the state of Virginia between June and November 2002 investigated causes of accidents (Warner, 2004). Following are some of the main factors that resulted in accidents, with the percentage of accidents for which each was responsible:

- rubbernecking (viewing accidents that have already occurred), 16%
- driver fatigue, 12%
- looking at scenery or landmarks, 10%
- distractions caused by passengers or children, 9%
- adjusting a radio or other media player, 7%
- cell phone use, 5%

On average, distractions occurring inside the vehicle accounted for 62% of the distractions reported. Distractions outside the vehicle accounted for 35%. The other 3% were of undetermined cause. The causes of accidents differed somewhat for rural versus urban areas. Accidents in rural areas were more likely to be due to driver fatigue, insects entering or striking the vehicle, or pet distractions. In urban areas, crashes were more likely to result from rubbernecking, traffic, or cell phone use (Cohen & Graham, 2003; Figure 4.11 ■).

As many as 21% of accidents and near-accidents involve at least one driver talking on a cell phone, although the conversation may or may not have been the cause of the accident (Seo & Torabi, 2004). Other research has indicated that, when time on task and driving conditions are controlled for, the effects of talking on a cell phone can be as

gazmandhu/Shutterstock

■ **Figure 4.11** **Divided Attention: Driving and Talking on the Cell Phone.** Illustrating a failure of divided attention, accidents often happen because drivers are engaged in other activities such as cell phone conversations. Drivers who rubberneck at the scene of an accident are another major cause of further accidents.

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detrimental as driving while intoxicated (Strayer, Drews, & Crouch, 2006). Still other research has found that, compared with people not on a cell phone, people talking on a cell phone exhibit more anger, through honking and facial expressions, when presented with a frustrating situation (McGarva, Ramsey, & Shear, 2006). Increased aggression has been linked with increased accidents (Deffenbacher et al., 2003). Therefore, it is likely that people who talk on the phone while driving are more prone to anger and, as a result, more accidents. These findings, combined with those on the effects of divided attention, help to explain why an increase in accidents is seen when cell phones are involved.

Nevertheless, the presence of a passenger in the car actually makes driving safer than driving alone. What is the difference between a cell phone conversation and a conversation with a passenger in a car? A study by Maciej, Nitsch, and Vollrath (2011) suggests that a passenger adjusts his speaking to the traffic situation, whereas a person on a cell phone obviously cannot know if his conversational partner is on an empty road or in heavy city traffic with black ice on the roads. Another study indicated that the more people actually speak on the cell phone, the less risky they perceive this behavior (Hallett, Lambert, & Regan, 2011).

Another high-risk behavior during driving is texting. When people engage in texting, the speed of their vehicle decreases significantly while at the same time their reaction time to road situations increases substantially. They are also at higher risk of having an accident because they are more distracted and react less quickly (Yannis et al., 2014). A survey of college students, however, found that 91% of students texted in their cars, and even did so when changing lanes or speeding, although they admitted they know about the dangers of texting while driving (Harrison, 2011).

Factors That Influence Our Ability to Pay Attention

The existing theoretical models of attention may be too simplistic and mechanistic to explain the complexities of attention. Many other variables have an impact on our ability to concentrate and pay attention. Here are some of them:

- *Anxiety:* Being anxious, either by nature (trait-based anxiety) or by situation (state-based anxiety), places constraints on attention (Eysenck & Byrne, 1992; Reinholdt-Dunne, Mogg, & Bradley, 2009).
- *Arousal:* Your overall state of **arousal** affects attention as well. You may be tired, drowsy, or drugged, which may limit attention. Being excited sometimes enhances attention (MacLean et al., 2009).
- *Task difficulty:* If you are working on a task that is difficult or novel for you, you'll need more attentional resources than when you work on an easy or highly familiar task. Task difficulty particularly influences performance during divided attention.
- *Skills:* The more practiced and skilled you are in performing a task, the more your attention is enhanced (Spelke, Hirst, & Neisser, 1976).

In sum, certain attentional processes occur outside our conscious awareness. Others are subject to conscious control. The psychological study of attention has included diverse phenomena, such as vigilance, search, selective attention, and divided attention, during the simultaneous performance of multiple tasks. To explain this diversity of attentional phenomena, current theories emphasize that a filtering mechanism appears to govern some aspects of attention. Limited modality-specific attentional resources appear to influence other aspects of attention. Clearly, findings from cognitive research have yielded many insights into attention, but additional understanding also has been gained through the study of attentional processes in the brain.

Neuroscience and Attention: A Network Model

Imagine how hard it is to synthesize all those diverse studies investigating the full range of attentional processes in the brain. Is attention a function of the entire brain, or is it a function of discrete attention-governing modules in the brain? According to Michael Posner, the attentional system in the brain "is neither a property of a single brain area nor of the entire brain" (Posner & Dehaene, 1994, p. 75). In 2007, Posner teamed up with Mary Rothbart and they conducted a review of neuroimaging studies in the area of attention to investigate whether the many diverse results of studies conducted pointed to a common direction. They found that what at first seemed like an unclear pattern of activation could be effectively organized into areas associated with the three subfunctions of attention: alerting, orienting, and executive attention. The researchers organized the findings to describe each of these functions in terms of the brain areas involved, the neurotransmitters that modulate the changes, and the results of dysfunction within this system.

Alerting: *Alerting* is defined as being prepared to attend to some incoming event, and maintaining this attention. Alerting also includes the process of getting to this state of preparedness. The brain areas involved in alerting are the right frontal and parietal cortexes as well as the locus coeruleus. The neurotransmitter norepinephrine is involved in the maintenance of alertness. If the alerting system does not work properly, people develop symptoms of ADHD; in the process of regular aging, dysfunctions of the alerting system may develop as well.

Orienting: *Orienting* is defined as the selection of stimuli to attend to. This kind of attention is needed when we perform a visual search. You may be able to observe this process by means of a person's eye movements, but sometimes attention is covert and cannot be observed from the outside. The orienting network develops during the first year of life. The brain areas involved in the orienting function are the superior parietal lobe, the temporal parietal junction, the frontal eye fields, and the superior colliculus. The modulating neurotransmitter for orienting is acetylcholine. Dysfunction within this system can be associated with autism.

Executive Attention: **Executive attention** includes processes for monitoring and resolving conflicts that arise among internal processes. These processes include thoughts, feelings, and responses. The brain areas involved in this final and highest order of attentional process are the anterior cingulate, lateral ventral, and prefrontal cortex as well as the basal ganglia. The neurotransmitter most involved in the executive attention process is dopamine. Dysfunction within this system is associated with Alzheimer's disease, borderline personality disorder, and schizophrenia.

When Our Attention Fails Us

The real importance of attention becomes clear in situations in which we cannot concentrate. Many studies involve normal participants. But cognitive neuropsychologists also have learned a great deal about attentional processes in the brain by studying people who do not show normal attentional processes, such as people who show specific attentional deficits and who are found to have either lesions or inadequate blood flow in key areas of the brain. Overall, attention deficits have been linked to lesions in the frontal lobe

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and in the basal ganglia (Lou, Henriksen, & Bruhn, 1984); visual attentional deficits have been linked to the posterior parietal cortex and the thalamus, as well as to areas of the midbrain related to eye movements (Posner & Petersen, 1990; Posner et al., 1988). Work with split-brain patients (e.g., Ladavas et al., 1994; Luck et al., 1989) also has led to some interesting findings regarding attention and brain function, such as the observation that the right hemisphere seems to be dominant for maintaining alertness and that the attentional systems involved in visual search seem to be distinct from other aspects of visual attention.

In the following sections, we will consider two examples of failing attention: (1) attention deficit hyperactivity disorder (ADHD) and (2) change blindness/inattentional blindness.

Attention Deficit Hyperactivity Disorder

Most of us take for granted our ability to pay attention and to divide our attention in adaptive ways. But not everyone can do so. People with ADHD have difficulties in focusing their attention in ways that enable them to adapt in optimal ways to their environment (*Attention Deficit Hyperactivity Disorder*, 2009; see also Swanson et al., 2003).

The condition was first described by Dr. Heinrich Hoffman in 1845. It has been investigated widely, but no one knows for sure the cause of ADHD. It may be a partially heritable condition. Some evidence indicates a link to maternal smoking and drinking during pregnancy (Hausknecht et al., 2005; Obel et al., 2009; Rodriguez & Bohlin, 2005). Childhood exposure to lead also may be associated with ADHD. Brain injury is another possible cause, as are food additives—in particular, sugar and certain dyes (Cruz & Bahna, 2006; Nigg et al., 2008). People with ADHD have noted differences in the frontal-subcortical cerebellar catecholaminergic circuits and in dopamine regulation (Biederman & Faraone, 2005).

The three primary symptoms of ADHD are inattention, hyperactivity (i.e., levels of activity that exceed what is normally shown by children of a given age), and impulsiveness. There are three main types of ADHD, depending on which symptoms are predominant: (1) hyperactive-impulsive, (2) inattentive, and (3) a combination of hyperactive-impulsive and inattentive behavior. We will focus on the inattentive type of behavior here because it is most relevant to the topic of this chapter.

Children with the inattentive type of ADHD show several distinctive symptoms:

- They are easily distracted by irrelevant sights and sounds.
- They often fail to pay attention to details.
- They are susceptible to making careless mistakes in their work.
- They often fail to read instructions completely or carefully.
- They are susceptible to forgetting or losing things they need for tasks, such as pencils or books.
- They tend to jump from one incomplete task to another.

Studies have shown that children with ADHD exhibit slower and more variable reaction times than their siblings who are not affected by the disorder (Andreou et al., 2007).

ADHD typically first displays itself during the preschool or early school years. It is estimated that about 5% of children worldwide have the disorder, although estimates range widely from less than 3% to more than 20% (Polanczyk & Jensen, 2008). The disorder does not typically end in adulthood, although it may vary in its severity, becoming either more or less severe. Some evidence suggests that the incidence of ADHD has increased in recent years. During the period from 2000 to 2005, the prevalence of medicinal treatment increased by more than 11% each year

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(Castle et al., 2007). The reasons for this increase are not clear. Various hypotheses have been put forward, including increased watching of fast-paced television shows, use of fast-paced video games, additives in foods, and increases in unknown toxins in the environment.

Researchers have found that ADHD and autism share some similarities and subsequently have conducted experiments to see how individuals with these two distinct syndromes differ in their ability to focus and pay attention. With respect to the network model described earlier, they found that children with ADHD have the most trouble in attentional orienting. Children with autism, on the contrary, show deficits in conflict monitoring and response preparation (Tye et al., 2014). They often become fixed in their attention on particular concepts or objects.

ADHD is most often treated with a combination of psychotherapy and drugs. Some of the drugs currently used to treat ADHD are Ritalin (methylphenidate), Metadate (methylphenidate), and Strattera (atomoxetine). This last drug differs from other drugs used to treat ADHD in that it is not a stimulant. Rather, it affects the neurotransmitter norepinephrine. The stimulants, in contrast, affect the neurotransmitter dopamine. Interestingly, in children, the rate of boys who are given medication for treatment of ADHD is more than double that of girls. In adults, however, the use of ADHD medication is approximately equal for both sexes (Castle et al., 2007). A number of studies have noted that, although medication is a useful tool in the treatment of ADHD, it is best used in combination with behavioral interventions (Corcoran & Dattalo, 2006; Rostain & Tamsay, 2006).

The theory of multiple intelligences (Gardner, 1985) has proven to be especially helpful in the treatment and support of children with ADHD. Gardner has suggested that intelligence includes multiple independent constructs, not just a single, unitary construct. Instead of speaking of multiple abilities that together constitute intelligence (e.g., Thurstone, 1938), this theory distinguishes eight distinct intelligences that are relatively independent of each other: linguistic, logical-mathematical, naturalist, interpersonal, intrapersonal, spatial, musical, and bodily kinesthetic intelligences. Each intelligence is alleged to form a separate system of functioning, although these systems can interact to produce what we see as intelligent performance. By concentrating on the students' abilities (or predominant intelligences) in educational interventions, the achievements of students with ADHD can be increased and their strengths can be emphasized (Davidson & Kemp, 2011; Schirduan & Case, 2004).

Change Blindness and Inattentional Blindness

Evolutionarily, our ability to spot predators as well as to detect food sources has been a great advantage for our survival. Adaptive behavior requires us to be attentive to changes in our environment because changes cue us to both opportunities and dangers. It thus may be surprising to discover that people can show remarkable levels of **change blindness**, that is, an inability to detect changes in objects or scenes that are being viewed (Galpin, Underwood, & Crundall, 2009; O'Regan, 2003). Closely related to change blindness is **inattentional blindness**, which is a phenomenon in which people are not able to see things that are actually there (Bressan & Pizzighello, 2008).

You can find some examples of change blindness and inattentional blindness in the vignette at the beginning of Chapter 1. Change and inattentional blindness are of major importance in traffic situations or during medical screenings, for example, in which an overlooked motorcycle or a mass in the body can have potentially fatal consequences. For more on change blindness, see Chapter 3. ■ Also explore Lab 9, Change Detection, in CogLab.

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Daniel Simmons

Change Blindness. Particpants were instructed to count the number of times participants wearing white passed the basketball. Many of them did not notice a gorilla walking through the players.

Source: The original selective attention task at www.theinvisiblegorilla.com/videos.html (first video).

Spatial Neglect—One Half of the World Goes Amiss

Imagine you are in a zoo with an acquaintance and you both look at the cages containing animals. Meanwhile, you are making comments to each other about the animals' behavior. You soon notice, however, that your friend is not aware of anything that is occurring in the left side of your visual fields. It is not only that he does not see the animals there, but he also is not even aware of their being there.

This condition is called *spatial neglect* or *hemineglect*. It is an attentional dysfunction in which participants ignore the half of their visual field that is contralateral to (on the opposite side of) the hemisphere of the brain that has a lesion. It is a result mainly of unilateral lesions in the parietal and frontal lobes, most often in the right hemisphere. To test those for spatial neglect, patients are given a sheet of paper with a number of horizontal lines. Patients are then asked to bisect the lines precisely in the middle of each. Patients with lesions in the right hemisphere tend to bisect the lines to the right of the midline. Patients with lesions in the left hemisphere tend to bisect the lines to the left of the midline. The reason is that the former group of patients does not see all of the lines to the left, whereas the latter group does not see all of the lines to the right. Sometimes patients miss the lines altogether (i.e., patients who neglect the entire visual field). If patients are asked to copy little pictures they are presented with, they often draw only one side of the picture (Figure 4.12 ■).

Interestingly, when patients are presented with stimuli only to their right or their left side, they often can perceive the stimuli, no matter which side they are on. This means that they have no major visual-field defects. When stimuli are present in both sides of the visual field, people with hemi-neglect suddenly ignore the stimuli that are contralateral to their lesion (i.e., if the lesion is in the right hemisphere, they neglect stimuli in the left visual field). This phenomenon is called *extinction*. The reason for extinction may be that patients are not able to disengage their attention from the stimulus in the ipsilateral field (the part of the visual field where the lesion is) in order then to shift their attention

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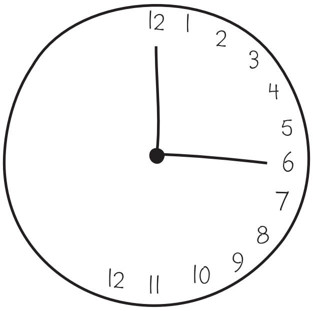
to the contralateral visual field. Their attention gets "stuck" on the ipsilateral object so that they cannot shift attention to stimuli that appear on the contralateral side. Fascinatingly, this finding holds true not only for people's perceptions in the external world but also for their memories.

A recent study found that people with spatial neglect also have trouble remembering events from their past. Think about a horizontal line as a timeline with the past to the left, the present in the middle, and the future to the right. The patients studied by Saj et al. (2014) had trouble representing the past—the left side of the timeline. These results indicate that some of the brain mechanisms needed for spatial visualization are also involved when it comes to the representation of temporal events.

In a 1978 study conducted by Bisiach and Luzzatti, participants with neglect were asked to describe the main square in their town. They described only one side of the square, although when asked to describe it from opposite ends, they demonstrated that they knew how both sides of the square looked.

There is no full consensus regarding which part of the brain is responsible for the symptoms of neglect. Recent studies indicate that the posterior superior temporal gyrus, insula, and basal ganglia, as well as the superior longitudinal fasciculus in the parietal lobe are most likely connected with spatial neglect (Hillis, 2006; Hillis et al., 2005; Karnath et al., 2004; Shinoura et al., 2009).



■ **Figure 4.12 Drawing by a Person with Hemispatial Neglect.** This drawing is from a patient who is suffering from neglect. As you can see, he ignores part of the clock.

CONCEPT CHECK

1. Why is attention important for humans?
2. What are the mistakes we can make when trying to detect a signal?
3. What is vigilance?
4. What is a feature search, and how does it differ from a conjunction search?
5. What is the difference between divided and selective attention?
6. What are filter theories of attention?

Automatic and Controlled Processes in Attention

As we have seen, our attention is capable of processing only so many things at once. Attentional filters enable us to process in depth what is important to us by filtering out irrelevant stimuli. To help us navigate our environment more successfully, we automatize many processes so that we can execute them without using up resources that then can be spent on other processes. Therefore, it is useful to differentiate cognitive processes in terms of whether they do or do not require conscious control (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Automatic and Controlled Processes

Automatic processes such as writing your name involve no conscious control (Palmeri, 2003). For the most part, they are performed without conscious awareness. Nevertheless, you may be aware that you are performing them. They demand little or

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no effort or even intention. Multiple automatic processes may occur at once, or at least quickly, and in no particular sequence. Thus, they are termed *parallel processes* (Posner & Snyder, 1975). You are able to read this text while at the same time sharpening your pencil and scratching your leg with your foot. Or have you ever found yourself in the shower, wondering whether you had already washed your hair? The process of washing your hair is so automatic, you may not even remember whether or not you washed your hair.

In contrast, **controlled processes** are accessible to conscious control and even require it. Such processes are performed serially, for example, when you want to compute the total cost of a trip you are about to book online. In other words, controlled processes occur sequentially, one step at a time. They take a relatively long time to execute, at least as compared with automatic processes. Table 4.3 ■ summarizes the characteristics of controlled versus automatic processes.

An alternative view of attention suggests a continuum of processes between fully automatic processes and fully controlled processes. For one thing, the range of controlled processes is so wide and diverse that it would be difficult to characterize all the controlled processes in the same way (Logan, 1988). Also, some automatic processes are

Table 4.3 **Controlled versus Automatic Processes**

There is probably a continuum of cognitive processes, from fully controlled processes to fully automatic ones; these features characterize the polar extremes of each.

Characteristics	Controlled Processes	Automatic Processes
Amount of intentional effort	Require intentional effort	Require little or no intention or effort (and intentional effort may even be required to avoid automatic behaviors)
Degree of conscious awareness	Require full conscious awareness	Generally occur outside of conscious awareness, although some automatic processes may be available to consciousness
Use of attentional resources	Consume many attentional resources	Consume negligible attentional resources
Type of processing	Performed serially (one step at a time)	Performed by parallel processing (i.e., with many operations occurring simultaneously or at least in no particular sequential order)
Speed of processing	Relatively time-consuming execution, as compared with automatic processes	Relatively fast
Relative novelty of tasks	Novel and unpracticed tasks or tasks with many variable features	Familiar and highly practiced tasks, with largely stable task characteristics
Level of processing	Relatively high levels of cognitive processing (requiring analysis or synthesis)	Relatively low levels of cognitive processing (minimal analysis or synthesis)
Difficulty of tasks	Usually difficult tasks	Usually relatively easy tasks, but even relatively complex tasks may be automatized, given sufficient practice
Process of acquisition	With practice, many routine and stable procedures may become automatized, such that highly controlled processes may become partly or even wholly automatic; the amount of practice needed for automatization increases for highly complex tasks	

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easy to retrieve into consciousness and can be controlled intentionally, whereas others are not accessible to consciousness or cannot be controlled intentionally.

Many tasks that start off as controlled processes eventually become automatic ones as a result of practice (LaBerge, 1975, 1990; Raz et al., 2007). This process is called **automatization** (also termed *proceduralization*). For example, driving a car is initially a controlled process. Once we master driving, however, it becomes automatic under normal driving conditions. Such conditions involve familiar roads, fair weather, and little or no traffic. Similarly, when you first learn to speak a foreign language, you need to translate word for word from your native tongue. Eventually, however, you begin to think in the second language. This thinking enables you to bypass the intermediate-translation stage. It also allows the process of speaking to become automatic. Your conscious attention can revert to the content, rather than the process, of speaking. A similar shift from conscious control to automatic processing occurs when acquiring the skill of reading. When conditions change, the same activity may again require conscious control. In the driving example, if the roads become icy, you will likely need to pay attention to when you need to brake or accelerate. Both tasks usually are automatic when driving.

How Does Automatization Occur?

How do processes become automatized? A widely accepted view has been that during the course of practice, implementation of the various steps becomes more efficient. A person gradually combines individual effortful steps into integrated components that are further integrated until the whole process is one single operation (Anderson, 1983; Raz et al., 2007). This operation requires few or no cognitive resources, such as attention. This view of automatization seems to be supported by one of the earliest studies of automatization (Bryan & Harter, 1899). This study investigated how telegraph operators gradually automatized the task of sending and receiving messages. Initially, new operators automatized the transmission of individual letters. Once the operators had made the transmission of letters automatic, however, they automatized the transmission of words, phrases, and then other groups of words.

An alternative explanation, called *instance theory*, was proposed by Logan (1988). Logan suggested that automatization occurs because we gradually accumulate knowledge about specific responses to specific stimuli. For example, when a child first learns to add or subtract, he or she applies a general procedure—counting—for handling each pair of numbers. Following repeated practice, the child gradually stores knowledge about particular pairs of particular numbers. Eventually, the child can retrieve from memory the specific answers to specific combinations of numbers. Nevertheless, he or she still can fall back on the general procedure (counting) as needed. Similarly, when learning to drive, a person can draw on an accumulated wealth of specific experiences. These experiences form a knowledge base from which the person quickly can retrieve specific procedures for responding to specific stimuli, such as oncoming cars or stoplights. Preliminary findings suggest that Logan's instance theory may better explain specific responses to specific stimuli, such as calculating arithmetic combinations (Logan, 1988).

The effects of practice on automatization show a negatively accelerated curve. In such a curve, early practice effects are great. Later practice effects make less and less difference in the degree of automatization. A graph of improvement in performance would show a steeply rising curve early on, and the curve would eventually level off (Figure 4.13 ■). Clearly, automatic processes generally govern familiar, well-practiced as well as easy tasks. Controlled processes govern relatively novel as well as difficult tasks. Because highly automatized behaviors require little effort or conscious control, we often

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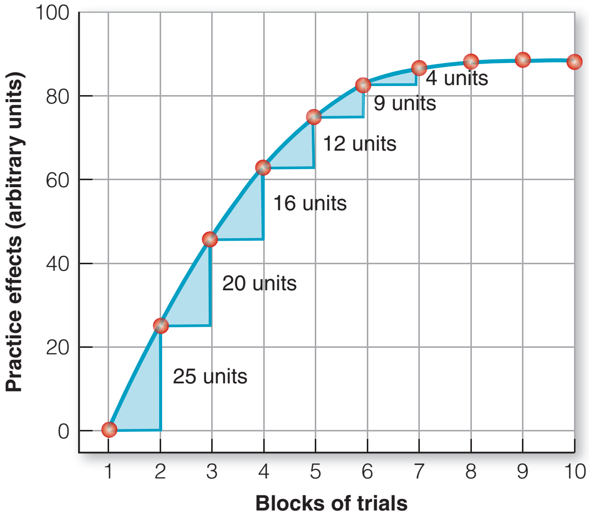


■ **Figure 4.13** **The Practice Effect.** The rate of improvement caused by practice effects shows a pattern of negative acceleration. The negative acceleration curve attributed to practice effects is similar to the curve shown here, indicating that the rate of learning slows down as the amount of learning increases, until eventually learning peaks at a stable level.

can engage in multiple automatic behaviors. But we rarely can engage in more than one labor-intensive controlled behavior.

Automatization in Everyday Life

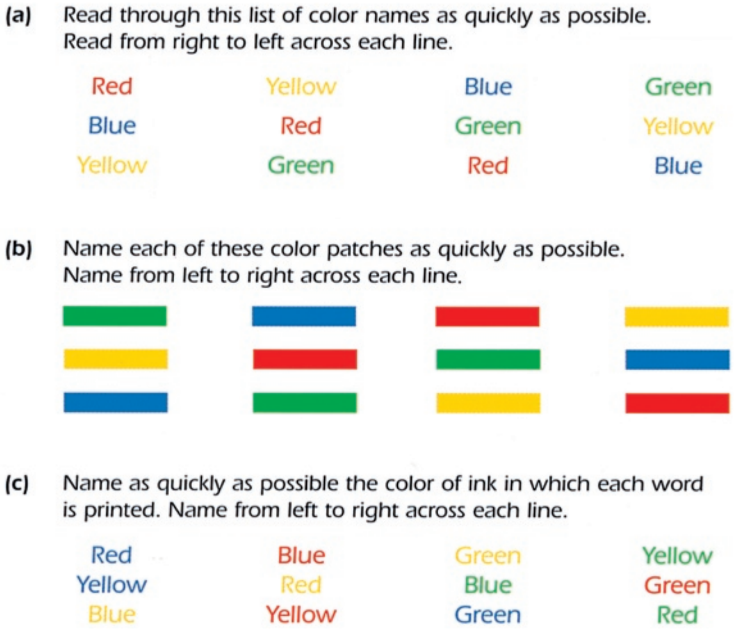
Automatization of tasks such as reading is not guaranteed, even with practice. In the case of dyslexia, for example, automatization is impaired. People who have dyslexia frequently have difficulty completing tasks, in addition to reading, that normally are automated (Brambati et al., 2006; Ramus et al., 2003; van der Leij, de Jong, & Rijswijk-Prins, 2001).

Sometimes, automatization in reading can work against us, however. One demonstration of this is the **Stroop effect**, which is named after John Ridley Stroop (1935). The task works as follows: Quickly read aloud the following words: brown, blue, green, red, purple. Easy, isn't it? Now quickly name aloud the colors shown Figure 4.14(a) ■. In this figure, the colored ink matches the name of the color word. This task, too, is easy. Now, look at Figure 4.14(c) ■. Here, the colors of the inks differ from the color names that are printed with them. Again, name the ink colors you see, out loud, as quickly as possible.

You probably will find the task difficult: Each of the written words interferes with your naming the color of the ink. The Stroop effect demonstrates the psychological difficulty in selectively attending to the color of the ink and trying to ignore the word that is printed with the ink of that color. One explanation of why the Stroop test may be particularly difficult is that, for you and most other adults, reading is now an automatic process. It is not readily subject to your conscious control (MacLeod, 1996, 2005). For that reason, you find it difficult not to read the words and instead to concentrate on identifying the color of the ink. An alternative explanation is that the output of a response occurs when the mental pathways for producing the response are activated sufficiently (MacLeod, 1991). In the Stroop test, the color word activates a cortical pathway for saying the word. In contrast, the ink-color name activates a pathway for naming the color. But the former pathway interferes with the latter. In this situation, it takes longer to gather sufficient strength of activation to produce the color-naming response and not the word-reading response.

THE STROOP EFFECT

In 1935, John Ridley Stroop observed a peculiar phenomenon of visual selective attention. Try implementing the set of tasks shown to the right. If you are like most people, you will find it more difficult to perform task c than either task a or task b. During the decades since the Stroop effect was first observed, many reasons have been proposed to explain it.


(a) Read through this list of color names as quickly as possible. Read from right to left across each line.

(b) Name each of these color patches as quickly as possible. Name from left to right across each line.

(c) Name as quickly as possible the color of ink in which each word is printed. Name from left to right across each line.

Figure 4.14 Stroop Effect. In 1935, John Ridley Stroop observed a peculiar phenomenon of visual selective attention. Try implementing the set of tasks shown to the right. If you are like most people, you will find it more difficult to perform task c than either task a or task b. During the decades since the Stroop effect was first observed, many reasons have been proposed to explain it.

A number of variations of the Stroop effect exist, including the number Stroop, the directional Stroop, the animal Stroop, and the emotional Stroop. Theses tasks are similar to the standard Stroop. For example, in the number Stroop, number words are used. Thus, the word *two* might be written three times, *two two two*, and the participant might be asked to count the number of words. As with the standard Stroop task, reading sometimes interferes with the counting task (Girelli et al., 2001; Kaufmann & Nuerk 2006). One of the most extensively used Stroop variations is the emotional Stroop. In this task, the standard task is modified so that the color words are replaced with either emotional or neutral words. Participants are asked to name the colors of the words. Researchers find that the delay is longer in color naming for emotional words as compared with neutral words. These findings suggest that the automatic reading of emotional words causes more interference than reading of neutral words (Bertsch et al., 2009; Phaf & Kan, 2007; Thomas, Johnstone, & Gonsalvez, 2007). 🟥 To try the Stroop task yourself, go to Lab 13, Stroop Effect, in CogLab.

In some situations, however, automatic processes may be life saving. Therefore, it is important to automate safety practices (Norman, 1976). This is particularly true for people engaging in high-risk occupations, such as pilots, undersea divers, and firefighters. For example, novice divers often complain about the frequent repetition of various safety procedures within the confines of a swimming pool, such as releasing a cumbersome weight belt. The practice is important, however, so the divers can rely on automatic processes in the face of potential panic should they confront a life-threatening deep-sea emergency.

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But in other situations automatization may result in "mindlessness" and may be life threatening (Kontogiannis & Malakis, 2009; Krieger, 2005; Langer, 1989, 1997): In 1982, a pilot and copilot went through a routine checklist before takeoff. They mindlessly noted that the anti-icer was "off," as it should be under most circumstances. But it should not have been off under the icy conditions in which they were preparing to fly. The flight ended in a crash that killed 74 passengers. Typically, our absentminded implementation of automatic processes has far less lethal consequences. For example, when driving, we may end up routinely driving home instead of stopping by the store, as we had intended to do. Or we may pour a glass of milk and then start to put the carton of milk in the cupboard rather than in the refrigerator.

Mistakes We Make in Automatic Processes

An extensive analysis of human error shows that errors can be classified either as mistakes or as slips (Reason, 1990). *Mistakes* are errors in choosing an objective or in specifying a means of achieving it. *Slips* are errors in carrying out an intended means for reaching an objective. Suppose you decided that you did not need to study for an examination. Thus, you purposely left your textbook behind when leaving for a long weekend. But then you discovered at the time of the exam that you should have studied. In Reason's terms, you made a mistake. Suppose instead, however, that you fully intended to bring your textbook with you. You had planned to study extensively over the long weekend, but in your haste to leave, you accidentally left the textbook behind. That would be a slip. In sum, mistakes involve errors in intentional, controlled processes. Slips often involve errors in automatic processes (Reason, 1990).

There are several kinds of slips (Norman, 1988; Reason, 1990; see Table 4.4 ■). In general, slips are most likely to happen when two circumstances occur. First is when we must deviate from a routine and automatic processes inappropriately override intentional, controlled processes. Second is when our automatic processes are interrupted. Such interruptions are usually a result of external events or data, but sometimes they are a result of internal events, such as highly distracting thoughts. Imagine that you are writing a paper after an argument with a friend. You may find yourself pausing in your writing as thoughts about what you should have said interrupt your normally automatic process of writing. Automatic processes are helpful to us under many circumstances. They save us from needlessly focusing attention on routine tasks, such as tying our shoes or dialing a familiar phone number. We are thus unlikely to forgo them just to avoid occasional slips. Instead, we should attempt to minimize the costs of these slips.

How can we minimize the potential for negative consequences of slips? In everyday situations, we are less likely to slip when we receive appropriate feedback from the environment. For example, the milk carton may be too tall for the cupboard shelf, or a passenger may say, "I thought you were stopping at the store before going home." If we can find ways to obtain useful feedback, we may be able to reduce the likelihood that harmful consequences will result from slips. A particularly helpful kind of feedback involves forcing functions. These are physical constraints that make it difficult or impossible to carry out an automatic behavior that may lead to a slip (Norman, 1988). For example, some modern cars make it difficult or impossible to drive the car without wearing a seatbelt. You can devise your own forcing functions. You may post a small sign on your steering wheel as a reminder to run an errand on the way home. Or you may put items in front of the door to block your exit so that you cannot leave without the items you want. Over a lifetime, we automatize countless everyday tasks.

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Table 4.4 Slips Associated with Automatic Processes

Occasionally, when we are distracted or interrupted during implementation of an automatic process, slips occur. In proportion to the number of times we engage in automatic processes each day, slips are relatively rare events (Reason, 1990).

Type of Error	Description of Error	Example of Error
Capture errors	Intending to deviate from a routine activity we are implementing in familiar surroundings, but at a point at which we should depart from the routine, we fail to pay attention and to regain control of the process; hence, the automatic process captures our behavior, and we fail to deviate from the routine.	Automatically following a usual routine, such as undressing from work clothes, then putting on pajamas and climbing into bed—only to realize you intended to remove your work clothes to dress to go out to dinner (James, 1890/1970, cited in Langer, 1989).
Omissions*	An interruption of a routine activity may cause us to skip a step(s) in implementing the remaining portion of the routine.	When going to another room to retrieve something, a distraction (e.g., a phone call) interrupts you and you return to the first room without retrieving the item.
Perseverations*	After completing an automatic procedure, one or more steps of the procedure may be repeated.	If, after starting a car, you become distracted, you may turn the ignition switch again.
Description errors	An internal description of the intended behavior leads to performing the correct action on the wrong object.	When putting away groceries, you may end up putting the ice cream in the cupboard and a can of soup in the freezer.
Data-driven errors	Incoming sensory information may override the intended variables in an automatic action sequence.	While intending to dial a familiar phone number, if you overhear someone call out another series of numbers, you dial some of those numbers instead.
Associative-activation errors	Strong associations may trigger the wrong automatic routine.	When expecting someone to arrive at the door, if the phone rings, you may call out, “Come in!”
Loss-of-activation errors	The activation of a routine may be insufficient to carry it through to completion.	Going to another room to do something and getting there only to ask ourselves, “What am I doing here?” Perhaps even worse is the nagging feeling, “I know I should be doing something, but I can’t remember what.” Something in the environment triggers our recollection.

*Omissions and perseverations may be considered examples of errors in the sequencing of automatic processes. Related errors include inappropriately sequencing the steps, as in trying to remove socks before taking off shoes.

Consciousness

Not everything we do, reason, and perceive is necessarily conscious. We may be unaware of stimuli that alter our perceptions and judgments or may be unable to come up with the right word in a sentence even though we know that we know the right word. This section will explore the consciousness of mental processes and how preconscious processing can influence our mind.

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The Consciousness of Mental Processes

No serious investigator of cognition believes that people have conscious access to simple mental processes. For example, none of us has a good idea of the means by which we recognize whether a printed letter such as *A* is an uppercase or lowercase one. But now consider more complex processing. How conscious are we of our complex mental processes? Cognitive psychologists have differing views on how this question is best answered.

One view (Ericsson & Simon, 1984) is that people have good access to their complex mental processes. Simon and his colleagues, for example, have used *protocol analysis* in analyzing people's solving of problems, such as chess problems and so-called cryptarithmetic problems, in which one has to figure out what numbers substitute for letters in a mathematical computation problem. These investigations have suggested to Simon and his colleagues that people have good conscious access to their complex information processes.

A second view is that people's access to their complex mental processes is not very good (e.g., Nisbett & Wilson, 1977). In this view, people may think they know how they solve complex problems, but their thoughts are frequently erroneous. According to Nisbett and Wilson, we typically are conscious of the products of our thinking, but only vaguely conscious, if at all, of the processes of thinking. For example, suppose you decide to buy one model of bicycle over another. You certainly will know the product of the decision—which model you bought. But you may have only a vague idea of how you arrived at that decision. Indeed, according to this view, you may believe you know why you made the decision, but that belief is likely to be flawed. Advertisers depend on this second view. They try to manipulate your thoughts and feelings toward a product so that, whatever your conscious thoughts may be, your unconscious ones will lead you to buy their product over that of a competitor. The essence of the second view is that people's conscious access to their thought processes, and even their control over their thought processes, is minimal (Levin, 2004; Wegner, 2002; Wilson, 2002). Consider the problem of getting over someone who has terminated an intimate relationship with you. One technique that is sometimes used to get over someone is thought suppression. As soon as you think of the person, you try to put the individual out of your mind. This technique has one problem, but it is a major one: It often does not work. Indeed, the more you try not to think about the person, the more you may end up thinking about him or her and having trouble getting the person off your mind. Research actually has shown that trying not to think about something usually does not work (Tomlinson et al., 2009; Wegner, 1997a, 1997b). Ironically, the more you try not to think about someone or something, the more "obsessed" you may become with the person or object.

Preconscious Processing

Some information that currently is outside our conscious awareness still may be available to consciousness or at least to cognitive processes. For example, when you comb your hair while getting ready for a first date, you still are able to do the combing, although your mind in all likelihood will be completely elsewhere, namely, on the date. The information about how to comb your hair is available to you even if you are not consciously combing. Information that is available for cognitive processing but that currently lies outside conscious awareness exists at the preconscious level of awareness. Preconscious information includes stored memories that we are not using at a given time but that we could summon when needed. For example, when prompted, you can remember what your bedroom looks like. But obviously you are not always consciously thinking about your bedroom (unless, perhaps, you are extremely tired). Sensations, too, may be pulled from preconscious to conscious awareness. For example, before you read this sentence, were you highly aware of the sensations in your right foot? Probably not. Those sensations, however, were available to you.

Studying the Preconscious—Priming

How can we study things that currently lie outside conscious awareness? Psychologists have solved this problem by studying a phenomenon known as priming. In **priming**, participants are presented with a first stimulus (the prime), followed by a break that can range from milliseconds to weeks or months. Then, the participants are presented with a second stimulus and make a judgment (e.g., are both the first and the second stimulus the same?) to see whether the presentation of the first stimulus affected the perception of the second (Neely, 2003). The thought behind this procedure is that the presentation of the first stimulus may activate related concepts in memory that are then more easily accessible. Suppose, for example, a friend is telling you about her vacation in Florida and how she loved to watch the cranes in the marshes. Later, you hear the word *crane*. You are probably more likely to think of the bird, as opposed to the machine used to move heavy objects, than is someone who did not hear the previous conversation about birding. Most priming is positive in that the first stimulus facilitates later recognition. But priming on occasion may be negative and impede later recognition. For example, if you are asked to solve several algebra problems that can be solved by the same formula, and then you are asked to solve another problem that requires another formula, you may be primed negatively relative to someone who did not solve the first set of problems with the now-irrelevant formula.

Sometimes we are aware of the priming stimuli. However, priming occurs even when the priming stimulus is presented in a way that does not permit its entry into conscious awareness (e.g., it is presented too briefly to be registered consciously).

Let us look at some studies that have used priming. Marcel (1983a, 1983b), for example, observed processing of stimuli that were presented too briefly to be detected in conscious awareness. In one study, Marcel presented participants with a prime that had two different meanings. One such prime could be the word *palm*, which can refer both to a body part and a plant. Afterward, participants were presented with another word that they were asked to classify into various categories. For participants who had *consciously* seen the prime, the mental pathway to one of the two meanings (e.g., plant) became activated and facilitated (speeded up) the classification of a subsequent *related* word. The pathway to the other meaning (e.g., body part) showed a negative priming effect in that it inhibited (slowed down) the classification of a subsequent *unrelated* word. For example, if the word *palm* was presented, the word either facilitated or inhibited the classification of the word *wrist*, depending on whether the participant associated *palm* with *hand* or with *tree*. In contrast, if the word *palm* was presented so briefly that the person was unaware of seeing the word, both meanings of the word appeared to be activated.

Another example of possible priming effects and preconscious processing can be found in a study described as a test of intuition. This study used a "dyad of triads" task (Bowers et al., 1990). Participants were presented with pairs (dyads) of three-word groups (triads; see Figure 4.15 ■). One of the triads in each dyad was a potentially coherent grouping. The other triad contained random and unrelated words. For example, the words in Group A, a coherent triad, might have been *playing, credit*, and *report*. The words in Group B, an incoherent triad, might have been *still, pages*, and *music*. (The words in Group A can be meaningfully paired with a fourth word—*card* [playing card, credit card, report card]; the words in Group B bear no such relationship.) After presentation of the dyad of triads, participants were shown various possible choices for a fourth word related to one of the two triads. The participants then were asked to identify which

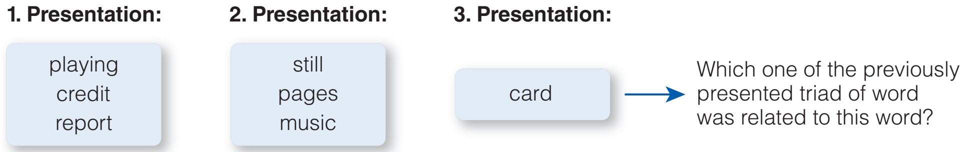


Figure 4.15 **The Dyad of Triads Task.** Participants in the dyad of triads task were presented with two 3-word groups (triads). One of those triads contained unrelated words; the other triad contained words that were coherent in some way. After seeing the two triads, participants were presented with another word and were asked to identify which triad was related to that word.

of the two triads was coherent and related to a fourth word, and which fourth word linked the coherent triad. Some participants could not figure out the unifying fourth word for a given pair of triads. Nevertheless, they were asked to indicate which of the two triads was coherent. When participants could not ascertain the unifying word, they still were able to identify the coherent triad at a level well above chance. They seemed to have some preconscious information available to them. This information led them to select one triad over the other. They did so even though they did not consciously know which word unified that triad.

The examples described here involve visual priming. Priming, however, does not have to be visual. Priming effects can be demonstrated using aural material as well. Experiments exploring auditory priming reveal the same behavioral effects as visual priming. Using neuroimaging methods, investigators have discovered that similar brain areas are involved in both types of priming (Badgaiyan, Schacter, & Alpert, 1999; Bergerbest, Ghahremani, & Gabrieli, 2004).

An interesting application of auditory priming was used with patients under anesthesia. While under anesthesia, these patients were presented with lists of words. After awakening from anesthesia, the patients were asked yes/no questions and word-stem completion questions about the words they heard. The patients performed at chance on the yes/no questions. They reported no conscious knowledge of the words. On the word-stem completion task, however, patients showed evidence of priming. The patients frequently completed the word-stems with the items they were presented while under anesthesia. These findings reveal that, even when the patient has absolutely no recollection of an aural event, the event still can affect performance (Deeprose et al., 2005).

What's That Word Again? The Tip-of-the-Tongue Phenomenon

Unfortunately, sometimes pulling preconscious information into conscious awareness is not easy. Most of you probably have experienced the **tip-of-the-tongue phenomenon**, in which you try to remember something that is stored in memory but that cannot readily be retrieved. Psychologists have tried to generate experiments that measure this phenomenon (e.g., see Hanley & Chapman, 2008). In one classic study (Brown & McNeill, 1966), participants were read a large number of dictionary definitions. For example, they might have been given the clue, "an instrument used by navigators to measure the angle between a heavenly body and a horizon." The subjects then were asked to identify the corresponding words having these meanings. This procedure constituted a game similar to the television show *Jeopardy*. Some participants could not come up with the word but thought they knew it. Still, they often could identify the first letter, the number of syllables, or approximate the word's sounds. For example, it begins with an *s*, has two syllables, and sounds like *sextet*. Eventually, some participants realized that the sought-after word was *sextant*. These results indicate that particular preconscious information, although not fully accessible to conscious thinking, is still available to attentional processes.

The tip-of-the-tongue phenomenon is apparently universal. It is seen in speakers of many different languages. Bilingual people experience more tip-of-the-tongues than monolingual speakers, which may be because bilinguals use either one of their languages less frequently than do monolinguals (Pyers, Gollan, & Emmorey, 2009). It also is seen in people with limited or no ability to read (Brennen, Vikan, & Dybdahl, 2007). Older adults have more tip-of-the-tongue experiences compared with younger adults (Galdo-Alvarez, Lindin, & Diaz, 2009; Gollan & Brown, 2006). The anterior cingulate-prefrontal cortices are involved when one is experiencing the tip-of-the-tongue phenomenon. This likely is due to high-level cognitive mechanisms being activated to resolve the retrieval failure (Maril, Wagner, & Schacter, 2001).

When Blind People Can See

Preconscious perception also has been observed in people who have lesions in some areas of the visual cortex (Rees, 2008; Ro & Rafal, 2006). Typically, the patients are blind in areas of the visual field that correspond to the lesioned areas of the cortex. Some of these patients, however, seem to show **blindsight**—traces of visual perceptual ability in blind areas (Kentridge, 2003). When forced to guess about a stimulus in the "blind" region, they correctly guess locations and orientations of objects at above-chance levels (Weiskrantz, 1994, 2009). Similarly, when forced to reach for objects in the blind area, "cortically blind participants . . . will nonetheless preadjust their hands appropriately to size, shape, orientation and 3-D location of that object in the blind field" (Marcel, 1986, p. 41). Yet they fail to show voluntary behavior, such as reaching for a glass of water in the blind region, even when they are thirsty. Some visual processing seems to occur even when participants have no conscious awareness of visual sensations.

An interesting example of blindsight can be found in a case study of a patient called D. B. (Weiskrantz, 2009). The patient was blind on the left side of his visual field as an unfortunate result of an operation. That is, each eye had a blind spot on the left side of its visual field. Consistent with this damage, D. B. reported no awareness of any objects placed on his left side or of any events that took place on this side. But despite his unawareness of vision on this side, there was evidence of vision. The investigator would present objects to the left side of the visual field and then present D. B. with a forced-choice test in which the patient had to indicate which of two objects had been presented to this side. D. B. performed at levels that were significantly better than chance. In other words, he "saw" despite his unawareness of seeing.

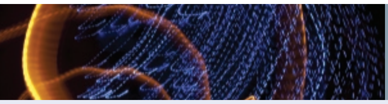
Another study paired presentations of a visual stimulus with electric shocks (Hamm et al., 2003). After multiple pairings, the patient began to experience fear when the visual stimulus was presented, even though he could not explain why he was afraid. Thus, the patient was processing visual information, although he could not see.

One explanation for blindsight is the following: The information from the retina is forwarded to the visual cortex, which is damaged in cortically blind people. It seems, however, that a part of the visual information bypasses the visual cortex and is sent to other locations in the cortex. The information from these locations is unconsciously accessible, although it seems to be conscious only when it is processed in the visual cortex (Weiskrantz, 2007).

The preceding examples show that at least some cognitive functions can occur outside of conscious awareness. We appear able to sense, perceive, and even respond to many stimuli that never enter our conscious awareness (Marcel, 1983a).

CONCEPT CHECK

1. How do mental processes become automated?
2. What is priming and how can it be studied?
3. What symptoms do patients have who exhibit blindsight?



Key Themes

The study of attention and consciousness highlights several key themes in cognitive psychology.

Structures versus processes. The brain contains various structures and systems of structures, such as the reticular activating system, that generate the processes that contribute to attention. Sometimes, the relationship between structure and process is not entirely clear, and it is the job of cognitive psychologists to better understand it. For example, blindsight is a phenomenon in which a process occurs—sight—in the absence of the structures in the brain that would seem to be necessary for the sight to take place.

Validity of causal inferences versus ecological validity. Should research on vigilance be conducted in a laboratory to achieve careful experimental control? Or should the research of high-stakes vigilance situations be studied ecologically? For example, a study in which military officers are examining radar screens for possible attacks against the country must have a high degree of ecological validity to ensure that the results apply to the actual situation in which the military officers find themselves. The stakes are too high to allow slippage. Yet, when vigilance in the actual-life situation is studied, one cannot and would not want to make attacks against the country happen. Therefore, it is necessary to use simulations that are as realistic as possible. In this way, the ecological validity of conclusions drawn can be ensured.

Biological versus behavioral methods. Blindsight is a case of a curious and as yet poorly understood link. The biology does not appear to be there to generate the behavior. Another interesting example is ADHD. Physicians now have available a number of drugs that treat ADHD. These treatments enable children as well as adults to focus better on the tasks that they need to get done. But the mechanisms by which the drugs work are poorly understood. Indeed, somewhat paradoxically, most of the drugs used to treat ADHD are stimulants, which, when given to children with ADHD, appear to calm them down.

SUMMARY

1. **Can we actively process information even if we are not aware of doing so? If so, what do we do, and how do we do it?** Whereas attention embraces all the information that an individual is manipulating (a portion of the information available from memory, sensation, and other cognitive processes), consciousness includes only the narrower range of information that the individual is aware of manipulating. Attention allows us to use our limited active cognitive resources (e.g., because of the limits of working memory) judiciously, to respond quickly and accurately to interesting stimuli, and to remember salient information.

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Conscious awareness allows us to monitor our interactions with the environment, to link our past and present experiences and thereby sense a continuous thread of experience, and to control and plan for future actions.

We actively can process information at the preconscious level without being aware of doing so. For example, researchers have studied the phenomenon of priming, in which a given stimulus increases the likelihood that a subsequent related (or identical) stimulus will be readily processed (e.g., retrieval from long-term memory). In contrast, in the tip-of-the-tongue phenomenon, another example of preconscious processing, retrieval of desired information from memory does not occur, despite an ability to retrieve related information.

Cognitive psychologists also observe distinctions in conscious versus preconscious attention by distinguishing between controlled and automatic processing in task performance. Controlled processes are relatively slow, sequential in nature, intentional (requiring effort), and under conscious control. Automatic processes are relatively fast, parallel in nature, and for the most part outside of conscious awareness. Actually, a continuum of processing appears to exist, from fully automatic to fully controlled processes.

2. **What are some of the functions of attention?** One main function involved in attention is identifying important objects and events in the environment. Researchers use measures from signal-detection theory to determine an observer's sensitivity to targets in various tasks. For example, vigilance refers to a person's ability to attend to a field of stimulation over a prolonged period, usually with the stimulus to be detected occurring only infrequently. Whereas vigilance involves passively waiting for an event to occur, search involves actively seeking out a stimulus.

   People use selective attention to track one message and simultaneously to ignore others. Auditory selective attention (such as in the cocktail party problem) may be observed by asking participants to shadow information presented dichotically. Visual selective attention may be observed in tasks involving the Stroop effect. Attentional processes also are involved during divided attention, when people attempt to handle more than one task at once; generally, the simultaneous performance of more than one automatized task is easier to handle than the simultaneous performance of more than one controlled task. With practice, however, individuals appear to be capable of handling more than one controlled task at a time, even engaging in tasks requiring comprehension and decision making.

3. **What are some theories cognitive psychologists have developed to explain attentional processes?** Some theories of attention involve an attentional filter or bottleneck, according to which information is selectively blocked out or attenuated as it passes from one level of processing to the next. Of the bottleneck theories, some suggest that the signal-blocking or signal-attenuating mechanism occurs just after sensation and before any perceptual processing; others propose a later mechanism, after at least some perceptual processing has occurred.

   Attentional-resource theories offer an alternative way of explaining attention; according to these theories, people have a fixed amount of attentional resources (perhaps modulated by sensory modalities) that they allocate according to the perceived task requirements. Resource theories and bottleneck theories actually may be complementary. In addition to these general theories of attention, some task-specific theories (e.g., feature-integration theory, and similarity theory) have attempted to explain search phenomena in particular.

4. **What have cognitive psychologists learned about attention by studying the human brain?** Early neuropsychological research led to the discovery of feature

detectors, and subsequent work has explored other aspects of feature detection and integration processes that may be involved in visual search. In addition, extensive research on attentional processes in the brain seems to suggest that the attentional system primarily involves two regions of the cortex, as well as the thalamus and some other subcortical structures; the attentional system also governs various specific processes that occur in many areas of the brain, particularly in the cerebral cortex. Attentional processes may be a result of heightened activation in some areas of the brain, of inhibited activity in other areas of the brain, or perhaps of some combination of activation and inhibition. Studies of responsivity to particular stimuli show that even when an individual is focused on a primary task and is not consciously aware of processing other stimuli, the brain of the individual automatically responds to infrequent, deviant stimuli (e.g., an odd tone). By using various approaches to the study of the brain (e.g., positron emission tomography, event-related potential, lesion studies, and psychopharmacological studies), researcher are gaining insight into diverse aspects of the brain and also are able to use converging operations to begin to explain some of the phenomena they observe.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe some of the evidence regarding the phenomena of priming and preconscious perception.
2. Compare and contrast the theories of visual search described in this chapter. Choose one of the theories of attention and explain how the evidence from signal detection, selective attention, or divided attention supports or challenges the theory.
3. Design one task likely to activate the posterior attentional system and another task likely to activate the anterior attentional system.
4. Design an experiment for studying divided attention.
5. How could advertisers use some of the principles of visual search or selective attention to increase the likelihood that people will notice their messages?
6. Describe some practical ways in which you can use forcing functions and other strategies for lessening the likelihood that automatic processes will have negative consequences for you in some of the situations you face.

KEY TERMS

arousal, p. 138
attention, p. 119
automatic processes, p. 143
automatization, p. 145
blindsight, p. 153
change blindness, p. 141
cocktail party problem, p. 127
conjunction search, p. 124
consciousness, p. 120
controlled processes, p. 144
dichotic presentation, p. 127
distracters, p. 124
divided attention, p. 133
executive attention, p. 139
feature-integration theory, p. 125
feature search, p. 124
inattentional blindness, p. 141
priming, p. 151
search, p. 124
selective attention, p. 127
signal, p. 121
signal detection, p. 121
signal-detection theory (SDT), p. 121
Stroop effect, p. 146
tip-of-the-tongue phenomenon, p. 152
vigilance, p. 123

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MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 13—Stroop Effect
Lab 9—Change Detection
Lab 8—Attentional Blink

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Memory: Models and Research Methods

5

CHAPTER OUTLINE

Tasks Used for Measuring Memory
  Recall versus Recognition Tasks
  Implicit versus Explicit Memory Tasks
Two Contrasting Models of Memory
  Atkinson and Shiffrin's Multistore Model
    Sensory Store
    Short-Term Store
    Long-Term Store
  The Levels-of-Processing Model
Working Memory: An Integrative Model
  The Components of Working Memory
  Neuroscience and Working Memory
  Measuring Working Memory
Other Models of Memory
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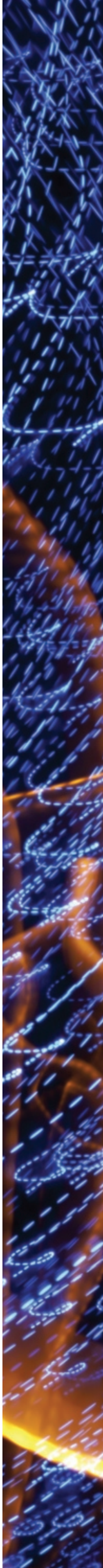
  A Connectionist Perspective
Exceptional Memory and Neuropsychology
  Outstanding Memory: Mnemonists
  Deficient Memory
    Amnesia
    Alzheimer's Disease
Key Themes
Summary
Thinking about Thinking: Analytical, Creative, and Practical Questions
Key Terms
Media Resources

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. What are some of the tasks used for studying memory, and what do various tasks indicate about the structure of memory?
2. What has been the prevailing traditional model for the structure of memory?
3. What are some of the main alternative models for the structure of memory?
4. What have psychologists learned about the structure of memory by studying exceptional memory and the physiology of the brain?

BELIEVE IT OR NOT

Memory Problems? How about Flying Less?

Travel across time zones can actually get you more than just an annoying jet lag. Researchers have found that people who are subjected to jet lag frequently with less than 2 weeks of recovery time perform worse on spatial memory tests than people who have more time to recover (Cho, 2001). Twenty flight attendants who serve on flights across more than seven time zones at a regular basis had MRI analyses to measure the size of their brains. It turned out that those flight attendants who had only 5 days to recover from jet lag, as opposed to 14 days, had a smaller temporal lobe, which is important to memory functions, and performed worse on the spatial memory tests. But why would the temporal lobe be smaller? Cho presumes that this is the result of elevated stress hormones: Flight attendants had significantly higher salivary cortisol levels after repeated long-distance flights than after short-distance flights, and cortisol is known to cause harm to the temporal lobe. You need not worry, however, unless you travel repeatedly across many time zones with few days to recover. People who may be affected, however, are shift workers, including doctors or nurses, because their day and night rhythms are frequently disrupted.

In this chapter, we will explore how our memory works and what factors improve or impair our memory performance.

Here are some questions. See if you can answer them:

- Who is the president of the United States?
- What is today's date?
- What did you have for breakfast?
- What does your best friend look like and what does your friend's voice sound like?
- What were some of your experiences when you first started college?
- How do you tie your shoelaces?

Those questions were pretty easy, right? Although retrieving the answers to these questions seemed easy, it is actually quite amazing that we can remember so many different facts and procedures without problems. In this chapter, we will see how we store information and retrieve it from memory.

As you age, your memory may change. As one author's grandmother got older, she gradually experienced a change in her memory. Memories from the grandmother's childhood and other details from her early and middle life were as vividly present as they

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had always been, but she had more and more problems remembering anything that had happened in the recent past (what she had for breakfast earlier in the day). She needed to ask her grandchildren several times during a visit how they were doing and where they were currently working, but she was quick to recall events that had happened to her when she was a middle-aged adult. Maybe one of your older relatives experienced memory issues such as these. But, what exactly is memory anyway?

Memory is the means by which we retain and draw on information from our past experiences to use in the present (Kandel, 2007; Tulving, 2000b; Tulving & Craik, 2000). As a process, memory refers to the dynamic mechanisms associated with storing, retaining, and retrieving information about past experience (Bjorklund, Schneider, & Hernández Blasi, 2003; Crowder, 1976). Specifically, cognitive psychologists have identified three common operations of memory: encoding, storage, and retrieval (Baddeley, 2002; Baddeley, Eysenck, & Anderson, 2009; Brebion et al., 2007; Brown & Craik, 2000). Each operation represents a stage in memory processing.

- In encoding, you transform sensory data into a form of mental representation.
- In storage, you keep encoded information in memory.
- In retrieval, you pull out or use information stored in memory. These memory processes are discussed at length in Chapter 6.

This chapter introduces some of the tasks that researchers use for studying memory. Then, we examine several models of how memory might work. First, we discuss the multistore model by Atkinson and Shiffrin (1968). This model includes the sensory, short-term, and long-term storage systems. Although this model still influences current thinking about memory, we consider some interesting alternative perspectives and models of memory before moving on to discuss exceptional memory and insights provided by neuropsychology.

Tasks Used for Measuring Memory

We begin this section with a discussion of how researchers study memory. When studying memory, researchers often use tasks that require participants to remember arbitrary information (e.g., numerals or letter strings) in different ways. Throughout this chapter, we refer to these tasks, which fall into two major categories—recall versus recognition memory and implicit versus explicit memory.

Recall versus Recognition Tasks

In **recall**, you produce a fact, a word, or other item from memory. Fill-in-the-blank and most essay tests require that you recall items from memory. For example, suppose you want to measure people's memory for late-night talk show hosts. You could ask people to name a television host. In **recognition**, you select or identify an item as being one that you have been exposed to previously. For example, you could ask people which of the following is a late-night show host: Jennifer Lopez, Jimmy Fallon, Guy Ritchie, or Cameron Diaz. Multiple-choice and true–false tests involve some degree of recognition. See Table 5.1 ■ for examples and explanations of each type of task.

Three main types of recall tasks are used in experiments (Lockhart, 2000): serial recall, free recall, and cued recall. In *serial recall,* you recall items in the exact order in which they were presented. For example, you could ask people to remember the following list of comedians *in order*: Stephen Colbert, Jon Stewart, David Letterman,

Table 5.1 Types of Tasks Used for Measuring Memory

Some memory tasks involve recall or recognition of explicit memory for declarative knowledge. Other tasks involve implicit memory and memory for procedural knowledge.

Memory Tasks	Description of What the Tasks Require	Example
Explicit-memory tasks	You must consciously recall particular information.	Who wrote *Hamlet?*
Declarative-knowledge tasks	You must recall facts.	What is your first name?
Recall tasks	You must produce a fact, a word, or other item from memory.	Fill-in-the-blank tests require that you recall items from memory. For example, "The term for persons who suffer severe memory impairment is ___."
Serial-recall task	You must repeat the items in a list in the exact order in which you heard or read them.	If you were shown the digits 2-8-7-1-6-4, you would be expected to repeat "2-8-7-1-6-4," in exactly that order.
Free-recall task	You must repeat the items in a list in any order in which you can recall them.	If you were presented with the word list "dog, pencil, time, hair, monkey, restaurant," you would receive full credit if you repeated "monkey, restaurant, dog, pencil, time, hair."
Cued-recall task	You must memorize a list of paired items; then when you are given one item in the pair, you must recall the mate for that item.	Suppose that you were given the following list of pairs: "time-city, mist-home, switch-paper, credit-day, fist-cloud, number-branch." Later, when you were given the stimulus "switch," you would be expected to say "paper," and so on.
Recognition tasks	You must select or otherwise identify an item as being one that you learned previously.	Multiple-choice and true-false tests involve recognition. For example, "The term for people with outstanding memory ability is (1) amnesics, (2) semanticists, (3) mnemonists, or (4) retrograders."
Implicit-memory tasks	You must draw on information in memory without consciously realizing that you are doing so.	Word-completion tasks tap implicit memory. You would be presented with a word fragment, such as the first three letters of a word; then you would be asked to complete the word fragment with the first word that comes to mind. For example, suppose that you were asked to supply the missing three letters to fill in these blanks and form a word: _e_or_. Because you had recently seen the word *memory,* you would be more likely to provide the three letters m-m-y for the blanks than would someone who had not recently been exposed to the word. (You have been "primed"; more on priming later in this chapter.)
Tasks involving procedural knowledge	You must remember learned skills and automatic behaviors, rather than facts.	If you were asked to demonstrate a "knowing-how" skill, you might be given experience in solving puzzles or in reading mirror writing, and then you would be asked to show what you remember of how to use those skills. Or you might be asked to master or to show what you already remember about particular motor skills (e.g., riding a bicycle or ice skating).

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Conan O'Brien, and Jimmy Fallon—and ask them then to repeat the list back in that order. ■ See also Lab 21, Position Error Effect, in CogLab.

The second kind of task is *free recall,* in which you recall items in any order you choose (Golomb et al., 2008). In this case, you would ask people to remember the list of comedians above, in any order.

The third kind of task is *cued recall,* in which you are first shown items in pairs, but during recall you are cued with only one member of each pair and are asked to recall each mate. Cued recall is also called "paired-associates recall" (Humphreys, Murray, & Koh, 2014). For example, you could ask people to learn the following pairings: Colbert–apple, Stewart–grape, Letterman–lemon, O'Brien–peach, Fallon–orange, and then ask them to produce the pairing for Stewart (grape).

Psychologists who study memory can also measure *relearning,* which is the number of trials it takes to learn once again items that were learned in the past. Relearning has also been referred to as savings and can be observed in adults, children, and animals (Bauer, 2005; Sasaki, 2008). The relearning effect was observed in fetal rats, whose limb movements were restrained by yokes and who were given kinesthetic feedback to influence their motor performance. These rats demonstrated shorter learning times for motor movements they previously had learned (Robinson, 2005). This effect is clearly and extensively generalizable to many situations and participants. For example, suppose you studied Spanish in high school and then did not study it again in college. You now need it to succeed on your job in communicating with customers. If you relearn Spanish, you will experience a savings in time relative to what you experienced the first time you learned it.

Recognition memory is usually much better than recall: We are better at recognizing things than at producing what exactly we saw or heard (although there are some exceptions, which are discussed in Chapter 6). You may have experienced the superiority of recognition memory when you answered an exam question requiring you to remember a fact (Brown, Roediger, & McDaniel, 2014). You were not able to produce all the facts that were asked for, but when you discussed that particular question with a fellow student after the exam and he pointed out the correct answer, you immediately recognized it as correct and were annoyed with yourself for not coming up with the answer while taking the test.

A study by Standing, Conezio, and Haber (1970) demonstrated that participants could recognize close to 2,000 pictures in a recognition-memory task. Although participants were able to recognize 2,000 pictures, they would not have been able to recall all of those pictures. It is difficult to imagine anyone recalling 2,000 items of any kind they were just asked to memorize. As you will see later in the section on exceptional memory, even with extensive training, the best-measured recall performance is typically around 80 items.

Informing participants of the type of test they will take can influence the amount of learning that occurs. Anticipating recall tasks generally elicits deeper levels of information processing than anticipating recognition tasks. For example, if you are going to have a French vocabulary test, you may study differently (and more intensively) if you need to recall English meanings of French words than if you merely have to say whether a set of English definitions of French words are correct or incorrect (recognition).

Some psychologists refer to recognition-memory tasks as tapping *receptive* knowledge. Receptive means "responsive to a stimulus." In a recognition-memory task, you respond to stimuli presented to you and decide whether you have seen them before or not. Recall-memory tasks, in which you have to produce an answer, require *expressive* knowledge. Differences between receptive and expressive knowledge also are observed in areas other than that of simple memory tasks (e.g., language, intelligence, and cognitive development).

Implicit versus Explicit Memory Tasks

Memory theorists distinguish between explicit memory and implicit memory (Mulligan, 2003). Each of the tasks previously discussed involves **explicit memory**, in which participants engage in conscious recollection. For example, they might recall or recognize words, facts, or pictures from a particular prior set of items.

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Implicit memory helps us to complete incomplete words we encounter without our even being consciously aware of it.

A related phenomenon is **implicit memory**, in which we use information from memory but are not consciously aware that we are doing so (Berry, Shanks, & Henson, 2008; McBride, 2007). You can read the word in the photo on the left without problems even though a letter is missing.

Every day you engage in many tasks that involve your unconscious recollection of information. Even as you read this book, you unconsciously are remembering various things—the meanings of particular words, some of the cognitive-psychological concepts you read about in earlier chapters, and even how to read. These recollections are aided by implicit memory. Explicit memory changes over the life span; implicit memory does not show the same changes. Specifically, infants and older adults often have relatively poor explicit memory, but implicit memory that is comparable to that of young adults (Carver & Bauer, 2001; Murphy, McKone, & Slee, 2003). People with certain disorders experience deficiencies in explicit memory with spared implicit memory; these groups will be discussed later in the chapter.

In the following section, we will examine two tasks that involve implicit memory—priming tasks and tasks involving procedural knowledge. We will then have a look at the process-dissociation model, which postulates that only one task is needed to measure both implicit and explicit memory.

In the laboratory, implicit memory is sometimes examined by having people perform word-completion tasks that are based on the *priming* effect. In a word completion task, participants receive a word fragment, such as the first three letters of a word. They then complete it with the first word that comes to mind. For example, suppose that you are asked to fill in the blanks with the five missing letters to form a word: imp_ _ _ _ _. Because you recently have seen the word *implicit,* you would be more likely to provide the five letters *l-i-c-i-t* for the blanks than would someone who had not recently been exposed to the word. You have been primed. Priming is the facilitation of your ability to utilize missing information. In general, participants perform better when they have seen the word on a recently presented list, although they have not been explicitly instructed to remember words from that list (Tulving, 2000a). Priming even works in situations in which you are not aware that you have seen the word before—that is, if the word was presented for a fraction of a second or in some other degraded form.

Procedural memory, or memory for processes, can be tested in implicit-memory tasks as well. Examples of procedural memory include the procedures involved in riding a bike or driving a car. Consider when you drive to the mall: You probably put the car into gear, use your blinkers, and stay in your lane without actively thinking about the task. Nor do you consciously need to remember what you should do at a red light. Many of the activities that we do every day fall under the purview of procedural memory; these can range from brushing your teeth to writing.

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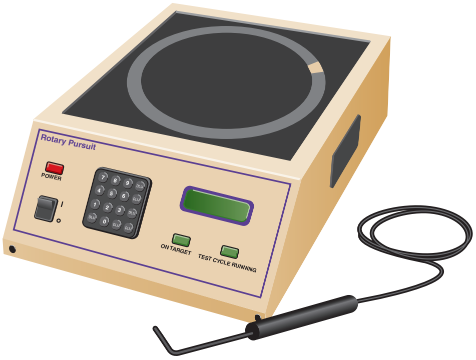
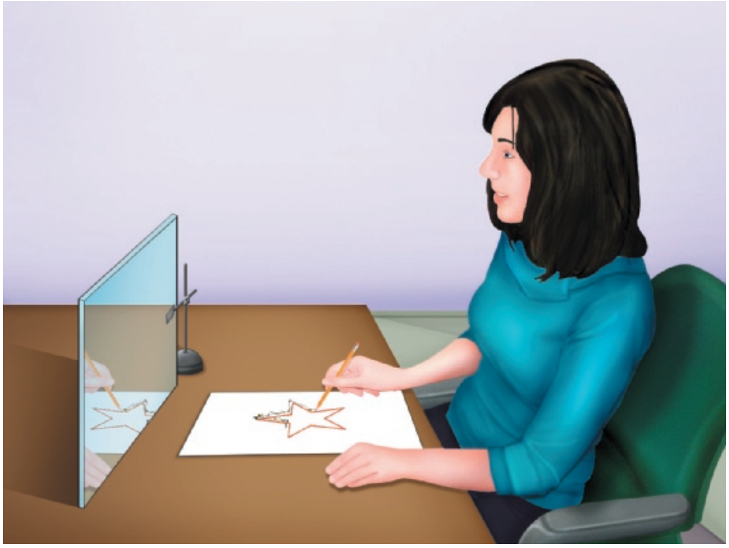
In the laboratory, procedural memory is sometimes examined with the rotary pursuit task (Gonzalez, 2008; see Figure 5.1 ■). The rotary pursuit task requires participants to maintain contact between an L-shaped stylus and a small rotating disk (Costello, 1967). The disk is generally the size of a nickel, less than an inch in diameter. This disk is placed on a quickly rotating platform. The participant must track the small disk with the wand as it quickly spins around on a platform. After learning with a specific disk and speed of rotation, participants are asked to complete the task again, either with the same disk and the same speed or with a new disk or speed. Verdolini-Marston and Balota (1994) noted that when a new disk or speed is used, participants do relatively poorly. But with the same disk and speed, participants do as well as they had after learning the task, even if they do not remember previously completing the task.

Another task used to examine procedural memory is mirror tracing (see Figure 5.2 ■). In the mirror-tracing task, a plate with the outline of a shape drawn on it is put behind a barrier where it cannot be seen. Beyond the barrier in the participant's line of sight is a mirror. When the participant reaches around the barrier, his or her hand and the plate with the shape are within view. Participants then take a stylus and trace the outline of the shape drawn on the plate. When first learning this task, participants have difficulty staying on the shape. Typically, there are many points at which the stylus leaves the outline. Moreover, it takes a relatively long time to trace the entire shape. With practice, however, participants become quite efficient and accurate with this task. Participants' retention of this skill gives us a way to study procedural memory (Rodrigue, Kennedy, & Raz, 2005).

The mirror-tracing task is also used to study the impact of sleep on procedural memory. Patients suffering from schizophrenia often have memory deficits as well as sleep problems. A study by Göder et al. (2008) found that when those patients received a medication that increased the duration of their slow-wave sleep, their procedural memory performance increased as well. A daytime nap also improved procedural performance in healthy participants but not in participants with schizophrenia (who were at the time of the study taking their regular medications; Seeck-Hirschner et al., 2010).



■ **Figure 5.1 The Rotary Pursuit Task.** In the rotary pursuit task, subjects use an *L*-shaped stylus to track a small, rotating disk on a spinning platform.



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■ **Figure 5.2 Mirror Tracing Task.** In the mirror tracing task, subjects trace the outline of a shape they can only see in a mirror.

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Are implicit and explicit memory separate and distinct aspects of memory? The methods for measuring both implicit and explicit memory described here and in Table 5.1 assume they are separate and can be measured by different tasks. Some researchers have challenged this assumption. They assume that both implicit and explicit memory play a role in every response, even if the task at hand is intended to measure only one type of memory. Thus, cognitive psychologists have developed models that assume that both implicit and explicit memory influence almost all responses. One of the first and most widely recognized models in this area is the *process-dissociation model* (Daniels, Toth, & Jacoby, 2006; Jacoby, 1991). The model assumes that implicit and explicit memory both have a role in virtually every response. Thus, only one task is needed to measure both of these processes.

Although theorists disagree about exactly what the different measures show, there is agreement that both implicit and explicit memory are important in our everyday lives. S. B. Kaufman (2010) also has argued that implicit memory, like explicit memory, is an important part of human intelligence.

CONCEPT CHECK

1. What is the difference between a recall task and a recognition task?
2. What is explicit memory?
3. What is implicit memory?
4. Why does it make sense to consider culture when doing research on memory in different countries?

Two Contrasting Models of Memory

Researchers have developed several models to describe how our memory works. In the following section, we first discuss the multistore model. Then we examine the levels-of-processing model and also consider an integrative model of working memory. Subsequently, we will explore some more conceptualizations of memory systems and lastly get to know a connectionist model. Let's begin with the traditional model of memory.

Atkinson and Shiffrin's Multistore Model

There are several major models of memory (Carey, 2014; Foster, 2008; McAfoose & Baune, 2009; Murdock, 2003). In the mid-1960s, based on the data available at the time, researchers proposed a model of memory distinguishing two structures of memory first proposed by William James (1890/1970): primary memory, which holds temporary information currently in use, and secondary memory, which holds information permanently or at least for a very long time (Waugh & Norman, 1965). Three years later, Richard Atkinson and Richard Shiffrin (1968) proposed an alternative model that conceptualized memory in terms of three memory stores:

- **sensory store:** capable of storing relatively limited amounts of information for very brief periods
- **short-term store:** capable of storing information for somewhat longer periods but of relatively limited capacity as well

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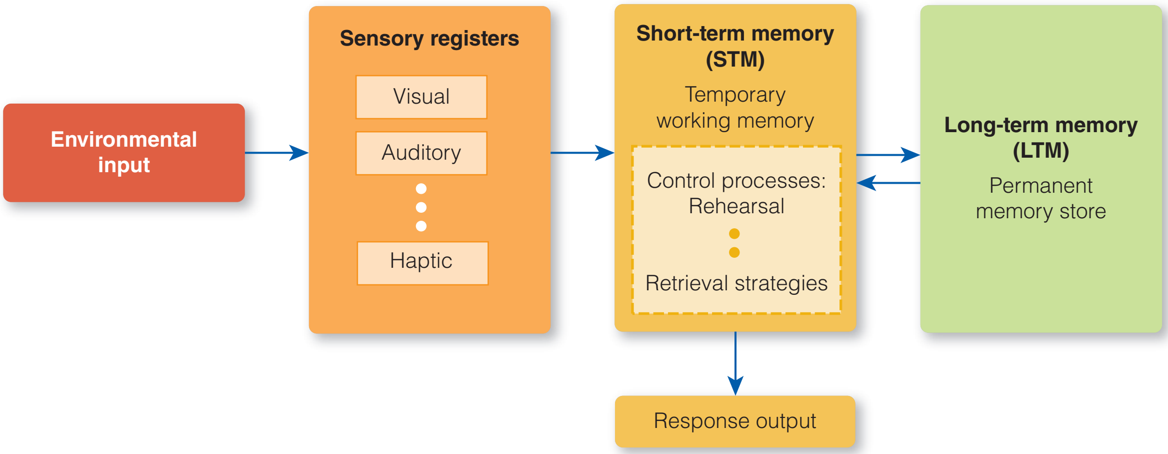

■ **Figure 5.3 Atkinson and Shiffrin's Memory Model.** Richard Atkinson and Richard Shiffrin proposed a theoretical model for the flow of information through the human information processor.

Source: Based on Allen Beechel, adapted from "The Control of Short-Term Memory," by Richard C. Atkinson and Richard M. Shiffrin.

- **long-term store:** capable of very large capacity and of storing information for very long periods, perhaps even indefinitely (Richardson-Klavehn & Bjork, 2003)

The model differentiates among structures for holding information, termed *stores,* and the information stored in the structures, termed *memory.* Atkinson and Shiffrin were not suggesting that the three stores are distinct physiological structures. Rather, the stores are **hypothetical constructs**—concepts that are not themselves directly measurable or observable but that serve as mental models for understanding how a psychological phenomenon works. Figure 5.3 ■ shows a simple information-processing model of these stores (Atkinson & Shiffrin, 1971). The model emphasizes the passive storage areas in which memories are stored, but it also alludes to some control processes that govern the transfer of information from one store to another.

Today, the three stores as are commonly described as sensory memory, short-term memory, and long-term memory. In the following sections, we take a closer look at the sensory store, the short-term store, and the long-term store.

Sensory Store

The *sensory store* (iconic store) is the initial repository of much information that eventually enters the shorthand long-term stores. Strong (although not undisputed; see Haber, 1983) evidence argues in favor of the existence of an iconic store. The **iconic store** is a discrete visual sensory register that holds information for very short periods. Its name derives from the fact that information is stored in the form of icons. These in turn are visual images that represent something. Icons usually resemble whatever is being represented.

If you have ever "written" your name with a lighted sparkler (or stick of incense) against a dark background, you have experienced the persistence of a visual memory. You briefly "see" your name, although the sparkler leaves no physical trace. This visual persistence is an example of the type of information held in the iconic store.

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Sperling's Discovery The existence of the iconic store was first discussed in a doctoral dissertation by a graduate student at Harvard University named George Sperling (1960). He addressed the question of how much information we can encode in a single, brief glance at a set of stimuli. Sperling flashed an array of letters and numbers on a screen for a mere 50 milliseconds (thousandths of a second). Participants were asked to report the identity and location of as many of the symbols as they could recall. Sperling could be sure that participants got only one glance because previous research had shown that 0.050 seconds is long enough for only a single glance at the presented stimulus.

Sperling found that when participants were asked to report on what they saw, they remembered only about four symbols. The finding confirmed an earlier one made by Brigden in 1933. The number of symbols recalled was pretty much the same, without regard to how many symbols had been in the visual display. Some of Sperling's participants mentioned that they had seen all the stimuli clearly. But while reporting what they saw, they forgot the other symbols that had been in the display. Sperling then conceived an ingenious idea for how to measure what the participants saw. The procedure used by Brigden and in the first set of studies by Sperling is a *whole-report procedure.* In this procedure, participants report *every* symbol they have seen. Sperling then introduced a *partial-report procedure.* Here, participants need to report only part of what they see.

Sperling found a way to obtain a sample of his participants' knowledge. He then extrapolated from this sample to estimate their total knowledge. His logic was similar to that of school examinations, which also are used as samples of an individual's total knowledge of course material. Sperling presented symbols in three rows of four symbols each. Figure 5.4 ■ shows a display similar to one that Sperling's participants might have seen. Sperling informed participants that they would have to recall only a single row of the display. The row to be recalled was signaled by a tone of high, medium, or low pitch. The pitches corresponded to the need to recall the top, middle, or bottom row, respectively.

To estimate the duration of iconic memory, Sperling manipulated the interval between the display and the tone. The range of the interval was from 0.10 seconds *before* the onset of the display to 1.0 second *after* the offset of the display. The partial-report procedure dramatically changed how much participants could recall. Sperling then multiplied the number of symbols recalled with this procedure by three. The reason was that participants had to recall only one-third of the information presented but did not know beforehand which of the three lines they would be asked to report.

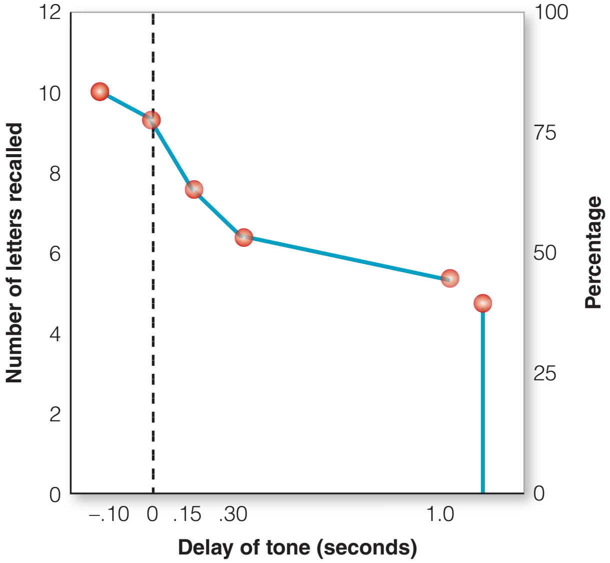
Using this partial-report procedure, Sperling found that participants had available roughly 9 of the 12 symbols if they were cued immediately before or immediately after the appearance of the display. However, when they were cued 1 second later, their recall was down to 4 or 5 of the 12 items. This level of recall was about the same as that obtained through the whole-report procedure. These data suggest that the iconic store can hold about nine items. They also suggest that information in this store decays very rapidly (Figure 5.5 ■). Indeed, the advantage of the partial-report procedure is reduced drastically by 0.3 seconds of delay. It essentially is obliterated by 1 second of delay for onset of the tone.

Sperling's results suggest that information fades rapidly from iconic storage. Why are we subjectively unaware of such a fading phenomenon? First, we rarely are subjected to stimuli such as the ones in his experiment. They appeared for only 50 milliseconds and then disappeared before participants needed to recall them. Second and more important, however, we are unable to distinguish what we see in iconic memory from what we actually see in the environment. What we see in iconic memory is what we take to be in the environment. Participants in Sperling's experiment generally reported that

H	B	S	T
A	H	M	G
E	L	W	C

■ **Figure 5.4 Display from a Visual-Recall Task.** This symbolic display is similar to the one used for George Sperling's visual-recall task.

Source: Based on *Psychology*, 2nd ed., by Margaret W. Matlin, Copyright © 1995 by Holt, Rinehart and Winston.



■ **Figure 5.5** **Results of Sperling's Experiment.** The figure shows the average number of letters recalled (left axis; percentage equivalents indicated on right axis) by a subject, based on using the partial-report procedure, as a function of the delay between the presentation of the letters and the tone signaling when to demonstrate recall. The bar at the lower-right corner indicates the average number of letters recalled when subjects used the whole-report procedure.

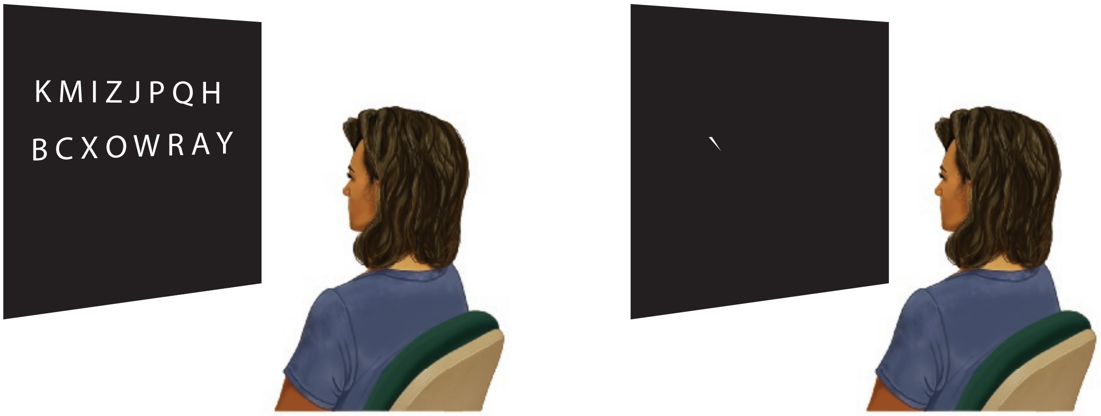
Source: After Sperling, 1960.

they could still see the display up to 150 milliseconds after it actually had been terminated. ■ See also Lab 18, Partial Report, in CogLab.

Elegant as it was, Sperling's use of the partial-report procedure was imperfect. It still suffered, at least to some small extent, from the problem inherent in the full-report procedure: Participants had to report multiple symbols. They may have experienced fading of memory during the report. Indeed, a distinct possibility of output interference exists. In this case, the production of output interferes with the phenomenon being studied. That is, verbally reporting multiple symbols may interfere with reports of iconic memory.

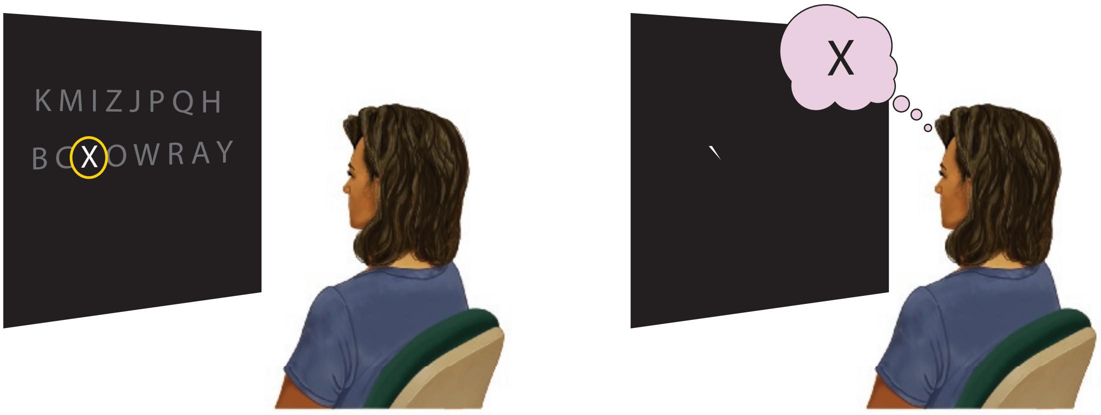
Subsequent Refinement In subsequent work, participants were shown displays of two rows of eight randomly chosen letters for a duration of 50 milliseconds (Averbach & Coriell, 1961). In this investigation, a small mark appeared just above one of the positions where a letter had appeared (or was about to appear; see Figure 5.6 ■). Its appearance was at varying time intervals before or after presentation of the letters. In this research, then, participants needed to report only a single letter at a time. The procedure thus minimized output interference. These investigators found that when the mark appeared immediately before or after the stimulus display, participants could report accurately on about 75% of the trials. Thus, they seemed to be holding about 12 items (75% of 16) in sensory memory. Sperling's estimate of the capacity of iconic memory, therefore, may have been conservative. The evidence in this study suggests that when output interference is greatly reduced, the estimates of the capacity of iconic memory may greatly increase. Iconic memory may account for as many as 12 items.

A second experiment (Averbach & Coriell, 1961) revealed an additional important characteristic of iconic memory: It can be erased. The erasable nature of iconic memory definitely makes our visual sensations more sensible. We would be in serious trouble if



(a) 16 letters (two rows of eight randomly chosen letters) are flashed on the screen for 50 milliseconds.

(b) Screen goes blank except for a small mark above one of the positions where a letter (in this case the letter X) had appeared.



(c) Participant is asked to recall which letter had been presented in the position of the small mark.

(d) Subjects were able to hold 75% of the items in sensory memory.

■ **Figure 5.6 Subsequent Refinement.** Recall was higher in the Averbach-Coriell procedure than in the Sperling procedure because of lesser output interference: Subjects had to recall just one letter.

everything we saw in our visual environment persisted for too long. For example, if we are scanning the environment at a rapid pace, we need the visual information to disappear quickly so that our memory does not get overloaded.

The investigators found that when a stimulus was presented after a target letter in the same position that the target letter had occupied, it could erase the visual icon (Averbach & Coriell, 1961). This interference is called backward visual masking. *Backward visual masking* is mental erasure of a stimulus caused by the placement of one stimulus where another one had appeared previously. If the mask stimulus is presented in the same location as a letter and within 100 milliseconds of the presentation of the letter, the mask is superimposed on the letter. For example, *F* followed by *L* would be *E*. At longer intervals between the target and the mask, the mask erases the original stimulus. For example, only the *L* would remain if *F* and then *L* had been presented. At still longer intervals between the target and the mask, the mask no longer interferes. This noninterference is

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presumably because the target information already has been transferred to more durable memory storage.

To summarize, visual information appears to enter our memory system through an iconic store. This store holds visual information for very short periods. In the normal course of events, this information may be transferred to another store. Or it may be erased. Erasure occurs if other information is superimposed on it before there is sufficient time for the transfer of the information to another memory store. Erasure or movement into another store also occurs with auditory information that is in echoic memory.

Short-Term Store

Most of us have little or no introspective access to our sensory memory stores. Nevertheless, we all have access to our short-term memory store. It holds memories for a few seconds and occasionally up to a couple of minutes. For example, can you remember the name of the researcher who discovered the iconic store? What about the names of the researchers who subsequently refined this work? If you can recall those names, you used some memory-control processes for doing so. According to the Atkinson–Shiffrin model, the short-term store does more than hold onto a few items. It also has some control processes available that regulate the flow of information to and from the long-term store, where we may hold information for longer periods. Typically, material remains in the short-term store for about 30 seconds, unless it is rehearsed to retain it. Information is stored acoustically (by the way it sounds) rather than visually (by the way it looks).

How many items of information can we hold in short-term memory at any one time? In general, our immediate (short-term) memory capacity for a wide range of items appears to be about seven items, plus or minus two (Miller, 1956). An item can be something simple, such as a digit, or something more complex, such as a word. If we chunk together a string of, say, 20 letters or numbers into 7 meaningful items, we can remember them. We could not, however, remember 20 items and repeat them immediately. For example, most of us cannot hold in short-term memory this string of 21 numbers: 101001000100001000100. However, if we chunk this string of numbers into larger units, such as 10, 100, 1,000, 10,000, 1,000, and 100, we probably will be able to reproduce easily the 21 numerals as 6 items (Miller, 1956).

Other factors also influence the capacity for temporary storage in memory. For example, the number of syllables we pronounce with each item affects the number of items we can recall. When each item has a larger number of syllables, we can recall fewer items (Hulme et al., 2006). In addition, any delay or interference can cause our seven-item capacity to drop to about three items. In general, the capacity limit may be closer to three to five than it is to seven (Cowan, 2001).

Most studies have used verbal stimuli to test the capacity of the short-term store, but people can also hold visual information in short-term memory. For example, they can hold information about shapes as well as their colors and orientations. What is the capacity of the short-term store of visual information? Is it less, the same, or perhaps greater? ■ See also Lab 17, Modality Effect, in CogLab.

A team of investigators set out to discover the capacity of the short-term store for visual information (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001). They presented experimental participants with two visual displays. The displays were presented in sequence. The stimuli were of three types: colored squares, black lines at varying orientations, and colored lines at different orientations. Thus, the third kind of stimulus combined the features of the first two. The kind of stimulus was the same in each of the two displays. For example, if the first display contained colored squares, so did the second. The two displays could be either the same or different from each other. If

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they were different, then it was by only one feature. The participants needed to indicate whether the two displays were the same or different. The investigators found that participants could hold roughly four items in memory, which were within the estimates suggested by Cowan (2001). The results were the same whether just individual features were varied (i.e., colored squares, black lines at varying orientation) or pairs of features were varied (i.e., colored lines at different orientations). Thus, storage seems to depend on numbers of objects rather than numbers of features.

This work contained a possible confound (i.e., other responsible factors that cannot be easily disentangled from the supposed causal factor). In the stimuli with colored lines at different orientations, the added feature was at the same spatial location as the original one. That is, color and orientation were, with respect to the same object, in the same place in the display. A further study thus was done to separate the effects of spatial location from number of objects (Lee & Chun, 2001). In this research, stimuli that included boxes and lines could be either at separate locations or at overlapping locations. The overlapping locations thus separated the objects from the fixed locations. The research would enable one to determine whether people can remember four objects, as suggested in the previous work, or four spatial locations. The results were the same as in the earlier research. Participants still could remember four objects, regardless of spatial locations. Therefore, memory was for objects, not spatial locations. Furthermore, using American Sign Language, researchers have found that short-term memory can hold approximately four items for signed letters. This finding is consistent with earlier work on visual-spatial short-term memory. The finding makes sense, given the visual nature of these items (Bavelier et al., 2006; Wilson & Emmorey, 2006).

Research on amnesia supports the distinction between short-term and long-term memory: Patients who have sustained damage to the hippocampus have difficulty in storing new information or retrieving old memories from their long-term store (Baddeley & Warrington, 1970). Patients whose perisylvian cortex has been damaged, however, can perform well on long-term memory tasks but have trouble keeping information in their short-term memory (Shallice & Warrington, 1970).

Long-Term Store

When most of us talk about memory, we usually are talking about long-term memory. Here we keep memories that stay with us over long periods, perhaps indefinitely. All of us rely heavily on our long-term memory. We hold in it information we need to get us by in our day-to-day lives—people's names, where we keep things, how we schedule ourselves on different days, and so on.

How much information can we hold in long-term memory? How long does the information last? The question of storage capacity can be disposed of quickly because the answer is simple. We do not know. Nor do we know how we would find out. We can design experiments to tax the limits of short-term memory, but we do not know how to test the limits of long-term memory and thereby find out its capacity. Some theorists have suggested that the capacity of long-term memory is infinite, at least in practical terms (Brady et al., 2008; Rose & Craik, 2012). It turns out that the question of how long information lasts in long-term memory is not easily answerable as well. At present, we have no proof even that there is an absolute outer limit to how long information can be stored.

What is stored in the brain? Wilder Penfield addressed this question while operating on the brains of conscious patients afflicted with epilepsy. He electrically stimulated various parts of the cerebral cortex to locate the origins of each patient's problem. In fact, his work was instrumental in plotting the motor and sensory areas of the cortex, described in Chapter 2.

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During the course of such stimulation, Penfield (1955, 1969) found that patients sometimes would appear to recall memories from their childhoods. These memories may not have been called to mind for many, many years. (Note that the patients could be stimulated to recall episodes such as events from their childhood, not facts such as the names of U.S. presidents.) These data suggested to Penfield that long-term memories might be permanent.

Some researchers have disputed Penfield's interpretations (e.g., Loftus & Loftus, 1980). For example, they have noted the small number of such reports in relation to the hundreds of patients on whom Penfield operated. In addition, we cannot be certain that the patients actually were recalling these events. They may have been inventing them. Other researchers, using empirical techniques on older participants, found contradictory evidence.

Some researchers tested participants' memory for names and photographs of their high-school classmates (Bahrick, Bahrick, & Wittlinger, 1975). Even after 25 years, there was little forgetting of some aspects of memory. Participants tended to recognize names as belonging to classmates rather than to outsiders. Recognition memory for matching names to graduation photos was quite high. As you might expect, recall of names showed a higher rate of forgetting.

The term *permastore* refers to the very long-term storage of information, such as knowledge of a foreign language (Bahrick, 1984a, 1984b; Bahrick et al., 1993) and of mathematics (Bahrick & Hall, 1991).

Schmidt et al. (2000) studied the permastore effect for names of streets near one's childhood homes. Indeed, the author just returned to his childhood home of more than 40 years ago and perfectly remembered the names of the nearby streets. These findings indicate that permastore can occur even for information that you have passively learned. Some researchers have suggested that permastore is a separate memory system. Others, such as Neisser (1999), have argued that one long-term memory system can account for both. There is to date no resolution of the issue.

Research on the immense capacity of long-term memory has motivated researchers, instructors, and teachers to come up with new methods to help students memorize what they learn. Students do have great memory capacity, and ideally, they should leave school with both the ability to think critically and also a good knowledge base about which to think. To this end, new and motivating techniques are constantly being developed and include online quizzes that students can take to test their knowledge, or the use of clickers (remote control devices that allow students to communicate with their teacher in front via a computer system) with which students can answer multiple-choice questions during class and can give feedback to the teacher (Miller, 2009).

The Levels-of-Processing Model

The **levels-of-processing (LOP) framework** is a radical departure from Atkinson and Shiffrin's multistore model of memory. The LOP framework suggests that memory does not comprise three or even any specific number of separate stores, but rather it varies along a continuous dimension in terms of depth of encoding (Craik & Lockhart, 1972, 2008). In other words, there are theoretically an infinite number of levels of processing (LOP) at which items can be encoded through elaboration—or successively deeper understanding of material to be learned. There are no distinct boundaries between one level and the next. This model emphasizes processing as the key to storage. The level at which information is stored will depend, in large part, on how it is encoded. Moreover, the deeper the level of processing, the higher, in general, is the probability that an item may be remembered (Craik & Brown, 2000). ■ See Lab 29, Levels of Processing, in CogLab.

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Table 5.2 **Levels-of-Processing Framework**

Among the levels of processing proposed by Fergus Craik and Endel Tulving are the physical, phonological, and semantic levels.

Level of Processing	Basis for Processing	Example
Physical	Visually apparent features of the letters	**Word:** TABLE **Question:** Is the word written in capital letters?
Phonological	Sound combinations associated with the letters (e.g., rhyming)	**Word:** CAT **Question:** DOES word rhyme with "MAT"?
Semantic	Meaning of the word	**Word:** DAFFODIL **Question:** Is the word a type of plant?

A set of experiments support the LOP view (Craik & Tulving, 1975). Participants received a list of words. A question preceded each word. Questions were varied to encourage item elaboration on three different levels of processing. In progressive order of depth, they were *physical, phonological,* and *semantic.* Samples of the words and the questions are shown in Table 5.2 ■. The results of the research were clear: The deeper the level of processing encouraged by the question, the higher the level of recall achieved. Similar results emerged in experiments independently conducted in Russia (Zinchenko, 1962, 1981).

The levels-of-processing framework also can be applied to nonverbal stimuli. Melinda Burgess and George Weaver (2003) showed participants photos of faces and asked them questions about the persons on the photo to induce either deep or shallow processing. Faces that were deeply processed were better recognized on a subsequent test than those that were studied at a lower level of processing. An LOP (or depth-of-processing) benefit can be seen for a variety of populations, including in people with schizophrenia. People suffering from schizophrenia often suffer from memory impairments because they do not process words semantically. Deeper processing helps them improve their memory (Ragland et al., 2003).

An even more powerful inducement to recall has been termed the self-reference effect (Rogers, Kuiper, & Kirker, 1977). In the *self-reference effect,* participants show very high levels of recall when asked to meaningfully relate words to themselves by determining whether the words describe them. Even the words that participants assess as not describing themselves are recalled at high levels. This high recall is a result of considering whether the words do or do not describe the participants. The highest levels of recall, however, occur with words that people consider self-descriptive. Many other researchers (e.g., Bower & Gilligan, 1979; Reeder, McCormick, & Esselman, 1987) have found similar self-reference effects. Objects can be better remembered, for example, if they belong to the participant (Cunningham et al., 2008). Some researchers suggest that the self-reference effect is distinctive, but others suggest that it is explained easily in terms of the LOP framework or other ordinary memory processes (e.g., Mills, 1983). For example, we have more elaborate encoding of information about ourselves because we know more about ourselves than about most people or things. Because our encoding is more elaborate, there are more retrieval pathways to lead to information about ourselves. Hence, we remember information about ourselves better. Each of us has an elaborate self-schema. This self-schema is an organized system of internal cues regarding our attributes, our personal experiences, and ourselves. Thus, we can richly and elaborately encode information related to ourselves much more so than information about other topics (Bellezza, 1984, 1992).

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INVESTIGATING COGNITIVE PSYCHOLOGY

Levels of Processing

Ask some friends or family members to help you with a memory experiment. Give half of them the instruction to count the number of letters in the words you are about to recite. Give the other half the instruction to think of three words related to the words you are about to recite. Recite the following words about 5 seconds apart: *beauty, ocean, competitor, bad, decent, happy, brave, beverage, artistic, dejected*. About 5 or 10 minutes later, ask your friends to write down as many of the 10 words as they can remember. In general, those who were asked to think of three related words to the words you read will remember more than those who were asked to count the number of letters in the words. This is a demonstration of levels of processing. Those friends who thought of three related words processed the words more deeply than those who merely counted up the number of letters in the words. Words that are processed more deeply are remembered better.

Despite much supporting evidence, the LOP framework as a whole has its critics. For one thing, some researchers suggest that the particular levels may involve a circular definition. On this view, the levels are defined as deeper because the information is retained better. But the information is viewed as being retained better because the levels are deeper. In addition, some researchers noted some paradoxes in retention. For example, under some circumstances, strategies that use rhymes have produced better retention than those using just semantic rehearsal. That means, focusing on superficial sounds and not underlying meanings can result in better retention than focusing on repetition of underlying meanings. But now imagine two conditions—one in which participants encode the information acoustically (based on rhymes) and retrieve it based on acoustic cues as well, and one in which participants both encode and retrieve the information semantically. For example, participants are presented with a word they will be asked to retrieve later, and then they have to determine whether that word rhymes with another word (acoustic encoding). For semantic encoding, they have to determine whether that word belongs to a given category or fits into a given sentence. Performance is greater for semantic retrieval than for acoustic retrieval (Fisher & Craik, 1977).

In light of these criticisms and some contrary findings, the LOP model has been revised. The sequence of the levels of encoding may not be as important as was thought before. Two other variables may be of more importance: the way people process (elaborate) the encoding of an item (e.g., phonological or semantic), and the way the item is retrieved later on. The better the match between the type of elaboration of the encoding and the type of task required for retrieval, the better the retrieval results (Morris, Bransford, & Franks, 1977).

Furthermore, there appear to be two kinds of strategies for elaborating the encoding. The first is within-item elaboration. It elaborates encoding of the particular item (e.g., a word or other fact) in terms of its characteristics, including the various levels of processing. The second kind of strategy is between-item elaboration. It elaborates encoding by relating each item's features (again, at various levels) to the features of items already in memory. Thus, suppose you wanted to be sure to remember something in particular. You could elaborate it at various levels for each of the two strategies.

Suppose, for example, you need to learn a list of words. Two of the words on the list are *dog* and *ball*. An example of within-item elaboration would be to imagine your dog Spot with his black fur, long snout, and floppy ears. You form a strong image of

practical applications of COGNITIVE PSYCHOLOGY

Elaboration Strategies

Elaboration strategies have practical applications: In studying, you may wish to match the way in which you encode the material to the way in which you will be expected to retrieve it in the future, because the better the match between the way you encode the material and the way you will need to retrieve it later, the better you are able to retrieve items from memory. For example, if you are learning a new language and have a vocabulary test coming up, you will concentrate on learning the meaning of the words. If you have to write an essay, you will also need to concentrate on sentence structure and grammar.

Also, the more elaborately and diversely you encode material, the more readily you are likely to recall it later in a variety of task settings. Just looking over material again and again in the same way is less likely to be productive for learning the material than is finding more than one way in which to learn it. If the context for retrieval will require you to have a deep understanding of the information, you should find ways to encode the material at deep levels of processing, such as by asking yourself meaningful questions about the material.

Are there any circumstances under which elaboration might be problematic?

Spot. That image will help you retrieve the word *dog*. An example of between-item encoding would be to imagine your dog Spot chasing after a ball and putting it in his mouth. The image of Spot putting the ball in his mouth helps you remember the words *dog* and *ball*.

Working Memory: An Integrative Model

The working-memory model is probably the most widely used and accepted model today. Psychologists who use it view short-term and long-term memory from a different perspective (e.g., Baddeley, 2007; Baddeley, Hitch, & Allen, 2009; Unsworth et al., 2009). In the traditional view, short-term memory serves only to store information for a short time. The working-memory concept, however, establishes a more dynamic view, whereby working memory serves not only to hold information but also to process that information. When you think about how you process language you hear or how you work on a problem in mathematics, this makes sense. Not only do you need to hold information in your memory, but somehow you also have to manipulate it. For example, we can remember about five or six unrelated words that are presented to us. However, if those words form a complete sentence that makes sense to us, then we can suddenly remember about 15 to 20 words. Suddenly our working memory can hold more items. This is because long-term memory (which stores the meaning of words) contributes to the performance of working memory (Rose & Craik, 2012). Therefore, the border between working memory and long-term memory is a lot fuzzier than the distinction between short-term memory and long-term memory in the three-store model.

Table 5.3 ■ shows the contrasts between the Atkinson–Shiffrin model and an alternative perspective. Note the semantic distinctions in how memory components are labeled, the differences in metaphorical representation, and the differences in emphasis for each view. The key feature of the working-memory model is the role of working memory. **Working memory** holds only the most recently activated, or conscious, portion of long-term memory, and it moves these activated elements into and out of brief, temporary

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Table 5.3 **Traditional versus Nontraditional Views of Memory**

Since Richard Atkinson and Richard Shiffrin first proposed their three-store model of memory (which may be considered a traditional view of memory), various other models have been suggested.

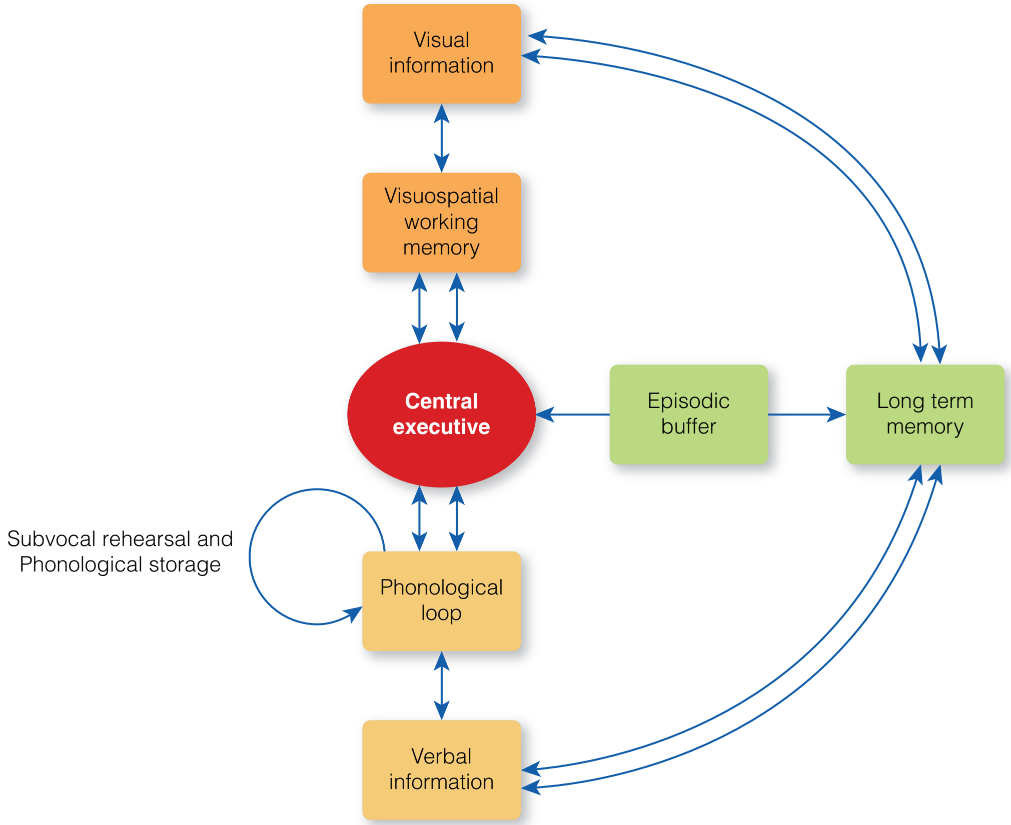
	Traditional Three-Store View	Working-Memory Model
Definition of memory stores	Working memory is another name for short-term memory, which is distinct from long-term memory.	Working memory (active memory) is that part of long-term memory that comprises all the knowledge of facts and procedures that recently has been activated in memory, including the brief, fleeting short-term memory and its contents.
Relationship between short-term/working and long-term memory	Short-term memory may be envisioned as being distinct from long-term memory, perhaps either alongside it or hierarchically linked to it.	Short-term memory, working memory, and long-term memory may be envisioned as nested concentric spheres, in which working memory contains only the most recently activated portion of long-term memory, and short-term memory contains only a very small, fleeting portion of working memory.
Information flow	Information moves directly from long-term memory to short-term memory and then back—never in both locations at once.	Information remains within long-term memory; when activated, information moves into long-term memory's specialized working memory, which actively will move information into and out of the short-term memory store contained within it.
Emphasis	Distinction between long- and short-term memory.	Role of activation in moving information into working memory and the role of working memory in memory processes.

memory storage (Dosher, 2003). Working memory is involved with the manipulation of information, whereas short-term memory serves only a storage purpose. Furthermore, working memory, in contrast with short-term memory, consists of several components (see Figure 5.7 ■).

The Components of Working Memory

One integrative model of memory, suggested by Alan Baddeley, combines the working-memory model with the LOP framework and provides an integrative model of memory (see Figure 5.7 ■; Baddeley, 1990a, 1990b, 2007, 2009). In this model, the LOP framework is an extension of, rather than a substitute for, the working-memory model.

Baddeley originally suggested that working memory comprises five elements: the visuospatial sketchpad, the phonological loop, the central executive, "subsidiary slave systems," and the episodic buffer. The first element, the **visuospatial sketchpad**, briefly holds some visual images, as when you picture the way your best friend looks or when you work on a puzzle. It contains both spatial and visual information, but some evidence indicates that actually two separate mechanisms within the visuospatial sketchpad deal with spatial and visual information. Information in the visuospatial sketchpad decays rapidly. We somehow rehearse the information to keep it from fading. It is not clear, however, how exactly we rehearse the visual and



■ **Figure 5.7** **Working Memory.** The components of the working-memory model are made up of the central executive, the phonological loop, the visuospatial sketchpad, and the episodic buffer, as well as several "subsidiary slave systems" (not pictured).

spatial information. Logie (1995) suggested that we have a "visual cache" that passively stores visual information, such as color and form. He further suggested we have an "inner scribe" that retains movement information and is responsible for rehearsal of the information.

The second element of working memory, the **phonological loop**, briefly stores mainly verbal information for verbal comprehension and for acoustic rehearsal. We use the phonological loop for a number of everyday tasks, including sounding out new and difficult words and solving word problems. This loop has two critical components: One component is *phonological storage*, which holds information in memory. Because trace decay (i.e., the fading of information in memory) occurs so quickly, we can store only about 2 seconds worth of speech-based information. The other component of the phonological loop is subvocal rehearsal, which holds information by nonverbally practicing it. Information is rehearsed here to prevent its fading in the phonological store. The subvocal rehearsal mechanism can also verbally label images we see; for example, when we see a picture of a flower we can label this image with the word *flower*, which is advantageous because sometimes we find it easier to remember verbal than visual information.

The role of subvocal rehearsal can be seen in the following example. Try to memorize the following list of words while repeating the number *five* to yourself continuously:

> Tree, pencil, marshmallow, lamp, sunglasses, computer, chocolate, noise, clock, snow, river, square, store

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Did you notice how hard it is to memorize these words? Try it again without repeating the number five to yourself. It should be much easier now! So what happens when you repeat the number five while memorizing words? In this case subvocal rehearsal is inhibited and you would be unable to rehearse the new words. When subvocal rehearsal is inhibited, the new information is not stored. This phenomenon is called *articulatory suppression*. Articulatory suppression is more pronounced when the information is presented visually versus aurally (e.g., by hearing). The amount of information that can be manipulated within the phonological loop is limited. Thus, we can remember fewer longer words compared with shorter words (Baddeley, 2000b) because it takes us longer to rehearse and produce the longer words. This phenomenon is called the *word length effect*. Without subvocal rehearsal, acoustic information decays after about 2 seconds. ■ See also Lab 26, Phonological Similarity Effect, in CogLab.

The third element of working memory is a **central executive**, which allocates attention within working memory. The central executive decides how to divide attention between two or more tasks that need to be done at the same time, or how to switch attention back and forth between multiple tasks. Baddeley believes different components may be responsible for focusing and dividing attention, but so far evidence is limited for his hypothesis (Baddeley, 2007). The central executive is critical to working memory because it is the gating mechanism that decides what information to process further and how to process this information. It decides what resources to allocate to memory and related tasks, and how to allocate them. It is also involved in higher-order reasoning and comprehension and is central to human intelligence. Studies have shown that long-term bilingualism strengthens the efficiency of the central executive. This is because bilingual individuals constantly need to control interference from the language they are not using at a given point in time. This control process uses a complex set of brain regions, including the anterior cingulate cortex, left prefrontal cortex, left inferior parietal lobule, and caudate. Incidentally, this same set of brain regions also is used by monolinguals when they experience conflict from competing responses or stimuli (Abutalebi & Green, 2007; Bialystock et al., 2014).

The fourth element is a number of other "subsidiary slave systems" that perform other cognitive or perceptual tasks (Baddeley, 1989, p. 36). The fifth element is the **episodic buffer**. A late addition to the working-memory model, it explains how we integrate information in working memory, long-term memory, the visuospatial sketchpad, and the phonological loop. This buffer allows us to solve problems and reevaluate previous experiences with more recent knowledge. The episodic buffer remains a rough concept, however, about which much still remains unknown (Baddeley, Eysenck, & Anderson, 2009).

Whereas the multistore view emphasizes the structural receptacles for stored information (a relatively passive task), the working-memory model underscores the functions of working memory in governing the processes of memory. These processes include encoding and integrating information. Examples include integrating acoustic and visual information through cross-modality, organizing information into meaningful chunks, and linking new information to existing forms of knowledge representation in long-term memory.

We can conceptualize the differing emphases with contrasting metaphors. For example, we can compare the three-store view to a warehouse in which information is passively stored. The sensory store serves as the loading dock. The short-term store includes the area surrounding the loading dock. Here, information is stored temporarily until it is moved to or from the correct location in the warehouse (long-term store).

A metaphor for the working-memory model might be a multimedia production house. It continuously generates and manipulates images and sounds. It also

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coordinates the integration of sights and sounds into meaningful arrangements. Once images, sounds, and other information are stored, they are still available for reformatting and reintegration in novel ways, as new demands and new information become available.

Working memory critically affects academic performance. A recent study of Brazilian schoolchildren assessed their working-memory skills (the ability to hold new information in their memory and manipulate that information) as well as their academic achievements. The study showed that working memory capacity is a good predictor of academic success (Engel de Abreu et al., 2014). These results also underscore the importance of early detection and intervention in children who may have weaker working-memory skills.

Baddeley's view of working memory is not the only model that scientists are currently investigating. Cowan (2005) suggested, for example, that working memory is embedded within long-term memory. In this view, the content of working memory is that part of long-term memory that is highly activated and therefore more accessible. Cowan believes that we can hold only four activated items (four "chunks") in our "focus of attention" (which is essentially our short-term memory). Some other researchers disagree and posit that we can hold only one chunk in our focus of attention and that all other information has to be retrieved from long-term memory (McElree, 2006; Oberauer, 2002, 2009). A recent study furthermore suggests that we should not see working memory as holding a fixed number of chunks but rather as a limited resource that is distributed between the different items that need to be held in memory. In this model, what matters most for retention is the quality of representation of an individual item in working memory (Ma, Husain, & Bays, 2014).

Neuroscience and Working Memory

Neuropsychological methods, and especially brain imaging, can be very helpful in understanding the nature of memory. Support for a distinction between working memory and long-term memory comes from neuropsychological research. Neuropsychological studies have shown abundant evidence of a brief memory buffer. The buffer is used to remember information temporarily. It is distinct from long-term memory, which is used to remember information for long periods (Rudner et al., 2007; Squire & Knowlton, 2000).

Furthermore, through some promising new research using positron emission tomography (PET) techniques, investigators have found evidence for distinct brain areas involved in the different aspects of working memory

A great deal of the neuroscientific work about visuospatial working memory was done with monkeys, whereas language is a uniquely human ability so that research on verbal working memory needs to be done with human participants by necessity (Buchsbaum & D'Esposito, 2014). One method that has been used frequently in studies on visuospatial working memory is the subtraction method (see also Chapter 2). A study by Jonides et al. (1993) presented participants with three dots in a square. They were asked to keep the location of these dots in their memory and after a delay were presented with a circle in another square. They needed to decide whether the circle enclosed one of the dots that had been memorized before (see Figure 5.8 ■). In a "memory scan," subjects were shown the three dots and instructed to keep their location in memory. In a "perception scan," the three dots and the circle were shown simultaneously, so that the participants just had to look whether a circle encircled one of the dots; in this condition, the subjects did not have to keep anything in memory. Subsequently, the results of the perception scans were subtracted from the results of the memory scans to eliminate any effects in the scans that had to do with perception alone. The resulting images therefore

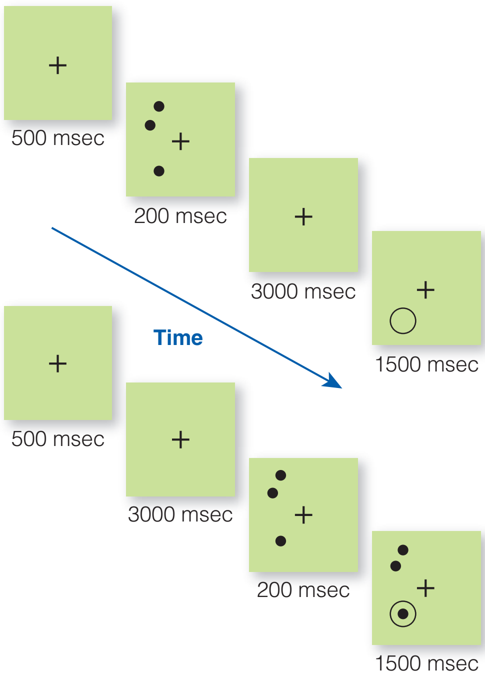

Figure 5.8 A Schematic Presentation of Spatial Memory Tasks. Subjects needed to decide whether the circle enclosed one of the dots that had been memorized before. Results of perception scans were subtracted from results of memory scans.

Source: Buchsbaum, B.R., & D'Esposito, M. (2014). Working memory. In *Oxford Handbook of Cognitive Neuroscience*, eds. K.N. Ochsner & S.M. Kosslyn. Oxford: Oxford University.

showed effects solely for visuospatial working memory. Generally, the investigators found that the prefrontal cortex, the posterior parietal lobe, the dorsal premotor cortex, and the occipital cortex (Brodmann area 19) are involved in visuospatial working memory. Which areas are activated depends on factors such as task difficulty and the length of the retention interval (Logie & Della Sala, 2005). Shorter intervals activate areas of the occipital and right frontal lobes. Longer intervals activate areas of the parietal and left frontal lobes (Haxby et al., 1995).

Studies have also shown that certain areas in the inferior temporal lobe respond not only preferentially to the presentation of certain object categories (such as faces) but also are activated when those objects are being kept in memory during working-memory tasks (e.g., see Druzgal & D'Esposito, 2003; Linden et al., 2003). One such area is the fusiform gyrus (also called *fusiform face area* [FFA]), which is activated to a greater extent when a person looks at faces as opposed to other objects such as houses. During working-memory tasks, the FFA consistently shows activity during a delay period in which subjects are asked to hold information in memory; the activity is selective for faces (Druzgal & D'Esposito, 2003; Postle, Druzgal, & D'Espoito, 2003). Also, the level of activity increases in magnitude as more faces need to be retained in memory (Druzgal & D'Esposito, 2001, 2003; Jha & McCarty, 2000). And in a delayed paired-associates task, the FFA even responds when an image of a house is presented that previously was associated with a particular face (Ranganath et al., 2004).

The phonological loop, maintaining speech-related information, appears to involve activation in the left hemisphere of the lateral frontal and inferior parietal lobes as well as the temporal lobe (Baddeley, 2006; Gazzaniga, Ivry, & Mangun, 2009). The first study

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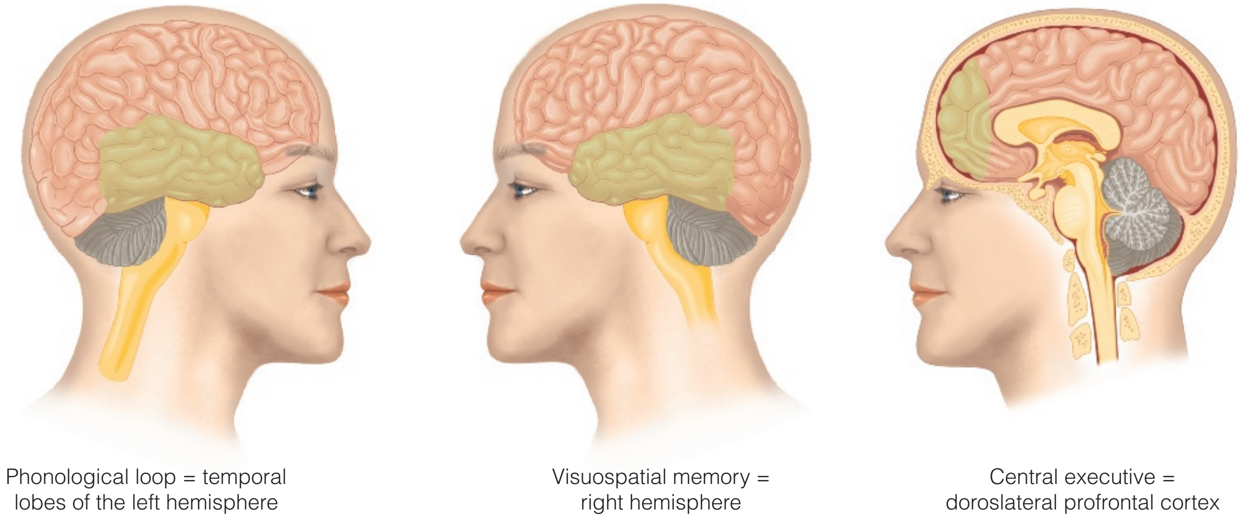
conducted on the location of the phonological loop used the subtraction method as well (Paulesu et al., 1993). Participants in a first task were presented with an English letter and asked to remember it. In a second task, they were shown an English letter and were asked if it rhymed with another letter. The reasoning behind the design of the study was that the first task engages subvocal rehearsal, phonological storage, and the central executive, whereas the second task does not engage phonological storage. In a baseline task, participants were presented with Korean letters and asked to remember those (a purely visual task). It was shown that, in general, the phonological tasks resulted in more activity in Broca's area (BA 44/45), Brodmann's areas 22/42 as well as 40, the insula, cerebellum, and supplementary motor cortex. When the rhyming (second) task results were subtracted from the results of the phonological (first) task, only one area was left to represent the phonological store: Brodmann area 40. Several later studies confirmed those findings (Awh et al., 1996; Schumacher et al., 1996; Smith & Jonides, 1999), pointing out that rehearsal mostly takes place in a frontal-insular cerebellar network, whereas the phonological store is located primarily in the parietal area. Later studies also have revealed that separate areas in the auditory association cortex are involved with different verbal qualities, such as voice information or phonological content (Martin & Freedman, 2001). ■ See also Lab 23, Irrelevant Speech Effect, in CogLab.

Relatively little is known about the central executive. The central executive functions appear to involve activation mostly in the frontal lobes (Baddeley, 2006; Roberts, Robbins, & Weiskrantz, 1996). The prefrontal cortex is involved with general tasks such as maintaining and controlling the information contained in working memory, no matter whether these tasks are visual or auditory (Buchsbaum & D'Esposito, 2014).

Finally, the episodic buffer operations seem to involve the bilateral activation of the frontal lobes and portions of the temporal lobes, including the left hippocampus (Rudner et al., 2007). Different aspects of working memory are represented in the brain differently. Figure 5.9 ■ shows some of these differences.


Phonological loop = temporal lobes of the left hemisphere
Visuospatial memory = right hemisphere
Central executive = doroslateral profrontal cortex

■ **Figure 5.9 The Brain and Working Memory.** Different areas of the cerebral cortex are involved in different aspects of working memory. The figure shows those aspects involved primarily in the articulatory loop, including phonological storage and subvocal rehearsal. Relevant areas are shown in olive green in the figure.

Source: Based on E. Awh et al. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science*, 7, 25–31. Copyright © 1996 by Blackwell, Inc.

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One conclusion we can draw from the research done so far is that brain regions that are involved in the perception of particular stimuli are also important for the maintenance of those stimuli in working memory. Working memory does not consist of one brain region but rather is represented across a variety of brain regions, such as the prefrontal cortex (which is important for active maintenance of internal representations) interacting with other posterior neocortical regions (Buchsbaum & D'Esposito, 2014).

Measuring Working Memory

Working memory can be measured through a number of different tasks. The most commonly used are shown in Figure 5.10 ■.

Task (a) is a retention-delay task. It is the simplest task shown in the figure. An item is shown—in this case, a geometric shape. (The + at the beginning is merely a focus point to indicate that the series of items is beginning.) There is then a retention interval, which may be filled with other tasks, or unfilled, in which case time passes without any specifically designed intervening activity. The participant is then presented with a stimulus and must say whether it is old or new. In the figure, the stimulus being tested is new. So "new" would be the correct answer.

Task (b) is a temporally ordered working memory load task. A series of items is presented. After a while, the series of asterisks indicates that a test item will be presented. The test item is presented, and the participant must say whether the item is old or new. Because "4," the number in the figure, has not been presented before, the correct answer is "new."

Task (c) is a temporal order task. A series of items is presented. Then the asterisks indicate a test item will be given. The test item shows two previously presented items, 3 and 7. The participant must indicate which of the two numbers, 3 or 7, appeared more recently. The correct answer is 7 because 7 occurred after 3 in the list.

Task (d) is an *n*-back task. Stimuli are presented. At specified points, one is asked to repeat the stimulus that occurred *n* presentations back. For example, one might be asked to repeat the digit that occurred 1 back—or just before (as with the 6). Or one might be asked to repeat the digit that occurred 2 back (as with the 7).

Task (e) is a temporally ordered working memory load task. It can also be referred to simply as a digit-span task (when digits are used). One is presented with a series of stimuli. After they are presented, one repeats them back in the order they were presented. A variant of this task has the participant repeat them back in the order opposite to that in which they were presented—from the end to the beginning.

Finally, Task (f) is a temporally ordered working memory load task. One is given a series of simple arithmetic problems. For each problem, one indicates whether the sum or difference is correct. At the end, one repeats the results of the arithmetic problems in their correct order.

Each of the tasks described here and in Figure 5.10 allows for the examination of how much information we can manipulate in memory. Frequently, these tasks are paired with a second task (called, appropriately, a *secondary task*) so that researchers can learn more about the central executive. The central executive is responsible for allocating attentional and other resources to ongoing tasks. By having participants do more than one task at once, we can examine how mental resources are assigned (Baudouin et al., 2006; D'Amico & Guarnera, 2005). A task that often is paired with those listed in Figure 5.10 is a random-number generation task. In this task, the participant must try to generate a random series of numbers while completing a working memory task (Rudkin, Pearson, & Logie, 2007).

■ See also Lab 24, Memory Span, in CogLab.

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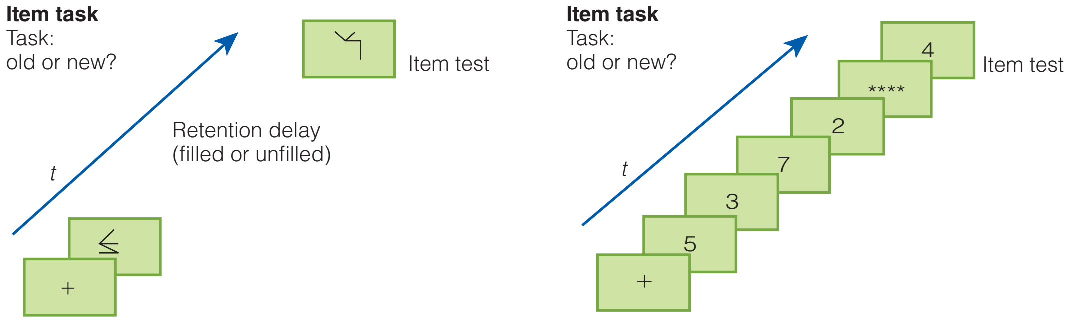
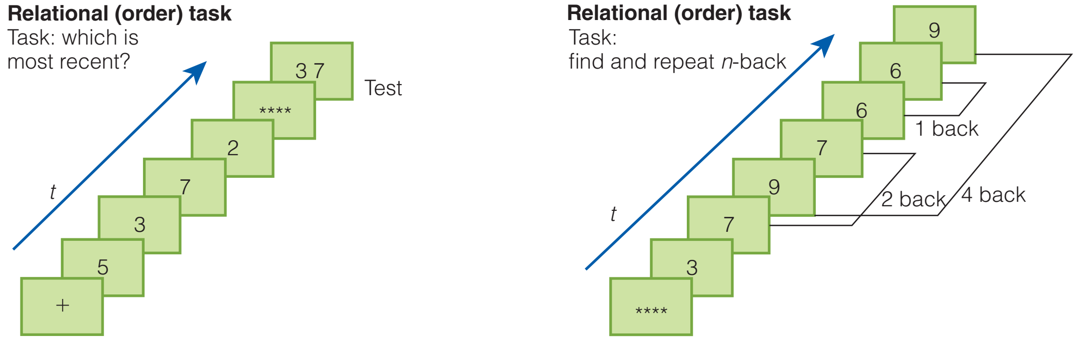

Item task
Task:
old or new?
Item test
Retention delay
(filled or unfilled)
t
+
Item task
Task:
old or new?
4
****
Item test
2
7
3
t
5
+

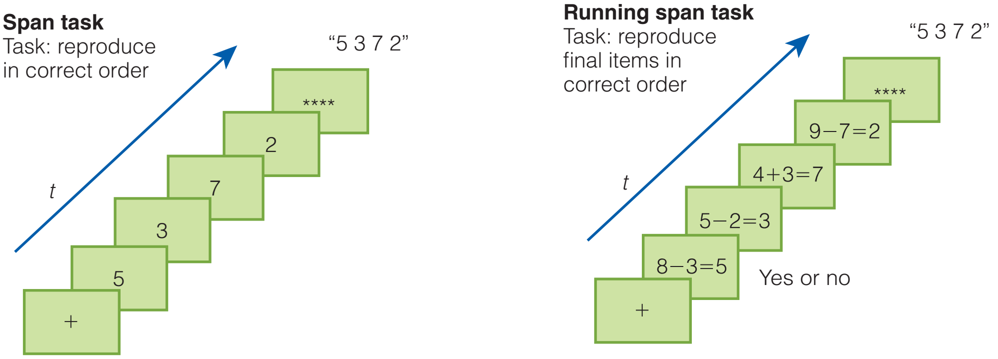
(a) Retention delay task

(b) Temporally ordered working memory load task


Relational (order) task
Task: which is
most recent?
3 7
Test
****
2
7
3
t
5
+
Relational (order) task
Task:
find and repeat n-back
9
6
6
1 back
7
9
2 back
4 back
t
7
3
****

(c) Temporal order task

(d) *n*-back task


Span task
Task: reproduce
in correct order
"5 3 7 2"
****
2
t
7
3
5
+
Running span task
Task: reproduce
final items in
correct order
"5 3 7 2"
****
9−7=2
t
4+3=7
5−2=3
8−3=5
Yes or no
+

(e) Temporally ordered working memory load task

(f) Temporally ordered working memory load task

■ **Figure 5.10 Tasks to Assess Working Memory.** Different kinds of tasks can be used to assess working memory. The squares in the image show the items that are presented to participants successively, starting at the lower left.

Source: Based on *Encyclopedia of Cognitive Science*, 4, p. 571. Copyright © 2003 B. Dosher.

Other Models of Memory

Multiple Memory Systems

The working-memory model is consistent with the notion that multiple systems may be involved in the storage and retrieval of information. Recall that when Wilder Penfield electrically stimulated the brains of his patients, the patients often said they vividly recalled particular episodes and events. They did not, however, recall semantic facts that were unrelated to any particular event. These findings suggest that there may be at least two separate explicit memory systems. One would be for organizing and storing information with a distinctive time referent. It would address questions such as "What did you eat for lunch yesterday?" or "Who was the first person you saw this morning?" The second system would be for information that has no particular time referent. It would address questions such as "Who were the two psychologists who first proposed the three-stores model of memory?" and "What is a mnemonist?"

On the basis of such findings, Endel Tulving (1972) proposed a distinction between two kinds of explicit memory. **Semantic memory** stores general world knowledge. It is our memory for facts that are not unique to us and that are not recalled in any particular temporal context. **Episodic memory** stores personally experienced events or episodes. According to Tulving, we use episodic memory when we learn lists of words or when we need to recall something that occurred to us at a particular time or in a particular context. In either case, we have personally experienced the learning as associated with a given time. The list we learn in the experiment, for example, is associated with the experiment as the context for learning. For example, suppose I needed to remember that I saw Harrison Hardimanowitz in the dentist's office yesterday. I would be drawing on an episodic memory. But if I needed to remember the name of the person I now see in the waiting room ("Harrison Hardimanowitz"), I would be drawing on a semantic memory. No particular time tag is associated with the name of that individual being Harrison. But a time tag is associated with my having seen him at the dentist's office yesterday.

The distinction between semantic and episodic memory is supported by cognitive research and neurological investigations by Tulving (1983, 1989) and others (e.g., Shoben, 1984). The neurological investigations have involved electrical-stimulation studies, studies of patients with memory disorders, and cerebral blood flow studies. For example, lesions in the frontal lobe appear to affect recollection regarding *when* a stimulus was presented. But they do not affect recall or recognition memory *that* a particular stimulus was presented (Schacter, 1989).

It is not clear, however, that semantic and episodic memories are two distinct systems. They sometimes appear to function in different ways. But many cognitive psychologists question this distinction (e.g., Eysenck & Keane, 1990; Humphreys, Bain, & Pike, 1989). They point out that the boundary between these two types of memory is often fuzzy. They also note methodological problems with some of the supportive evidence. Perhaps episodic memory is merely a specialized form of semantic memory (Tulving, 1984, 1986).

Some neurological evidence suggests that these two types of memory are separate, however. Through neuropsychological methods, investigators found dissociations, which means that separate and distinct areas seem to be involved in semantic versus episodic memory retrieval (Prince, Tsukiura, & Cabeza, 2007). When researchers find neural substrates of particular brain functions, one speaks about *dissociation*. There are patients who suffer only from loss of semantic memory, but their episodic memory is not impaired, and vice versa (Temple & Richardson, 2004; Vargha-Khadem et al., 1997). A person with semantic memory loss may have trouble remembering what date it is or who the current president is; a person with episodic memory loss cannot remember personal events such as where he or she met a spouse for the first time. These observations indicate that there is a dissociation between the two kinds of memory. These findings all support the conclusion that episodic and semantic memory systems are separate.

A neuroscientific model called *HERA* (hemispheric encoding/retrieval asymmetry) attempts to account for differences in hemispheric activation for semantic versus episodic memories. According to this model, there is greater activation in the left prefrontal

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in the lab of **MARCIA K. JOHNSON**

Memory and the Brain

Courtesy of the author

Marcia K. Johnson

How do we know that a mental experience is a *memory* for a particular event, rather than a mix of elements from past events, or a product of current or past imagination, second-hand knowledge, belief, or wishful thinking? In fact, we can't be sure. Integrating information across experiences is the basis of complex thought, but this capacity for creative integration can generate source misattributions, for example, attributing an imagination to perception, an intention to an action, something heard to something witnessed, something read in a tabloid to a television news program, or an incident that occurred in place *A* or at time *A* to place *B* or time *B*. False memories can be minor (e.g., believing one last saw the car keys in the kitchen when they were in the bedroom) or have profound implications (e.g., mistakenly claiming to be the originator of an idea or that one was sexually abused as a child). Cognitive behavioral studies provide evidence about the conditions that affect source memory and thus help explicate the cognitive processes involved.

A better understanding of source memory also comes from labs using neuroimaging (e.g., functional magnetic resonance imaging [fMRI]) to identify brain regions corresponding to cognitive processes that encode different features of events (e.g., scenes [parahippocampal gyrus, PHG], faces [fusiform gyrus, FG], lateral occipital cortex [objects, LOC]), and the regions involved in binding these features together (hippocampus) and rerepresenting them as conscious experience and making judgments about them (frontal and parietal cortex). For example, some brain regions (PHG) show similar patterns of activation when you perceive something (a photo of a beach) and when you think of it. Further clarifying the nature of the similarity in perceptual and reflective representations is an important target for future research. We and others are also investigating how ratings of memory vividness relate to patterns of brain activity, and how brain activity during remembering is affected by participants' goals.

Several types of evidence indicate that the prefrontal cortex (PFC) plays a key role both in binding features of stimuli together during encoding, and in later activating complex representations and in identifying the sources of aspects of these mental experiences. Damage to the PFC produces deficits in source memory. Source memory errors are more likely in children (whose frontal lobes are slow to develop) and in older adults (who are likely to show increased neuropathology in PFC with age). PFC dysfunction may also play a role in schizophrenia, which sometimes includes source-monitoring deficits in the form of delusions or hallucinations. Neuroimaging is helping to clarify the specific functions of PFC in source memory.

For example, in one type of study, participants see two types of items (e.g., pictures and words). Later they are shown three kinds of words: words that correspond to the pictures seen earlier, words seen earlier as words, and new words that do not correspond to any of the items seen earlier (new items). If participants are asked to identify the source of items (say whether an item was shown as a picture or word, or was new), there typically is greater activity in the PFC than if they are only asked to identify whether an item is familiar or not (respond "old" to items shown as pictures or words or say "new"). Studies from our lab and other labs suggest that both right and left PFC contribute to evaluating the origin of mental experiences, possibly in different ways (e.g., engaging different processes or monitoring different types of information), and interactions between the right and left hemispheres are likely important. One goal for future research is to relate specific component processes of cognition to patterns of activity across various regions of the PFC and to specify how PFC regions interact with other brain regions (e.g., the hippocampus and parietal cortex and representational areas such as PHG or LOC) in producing the subjective experiences we take to be memories.

Suggested Readings

Johnson, M. K. (2006). Memory and reality. *American Psychologist, 61,* 760–771.

Johnson, M. R., & Johnson, M. K. (2014). Decoding individual natural scene representations during perception and imagery. *Frontiers in Human Neuroscience, 8,* 59.

(continued)

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in the lab of **MARCIA K. JOHNSON**

Johnson, M. K., Kuhl, B. A., Mitchell, K. J., Ankudowich, E., & Durbin, K. A. (2015). Age-related differences in the neural basis of the subjective vividness of memories: Evidence from multivoxel pattern classification. *Cognitive, Affective & Behavioral Neuroscience*. doi:10.3758/s13415-015-0352-9

Johnson, M. K., Raye, C. L., Mitchell, K. J., & Ankudowich, E. (2011). The cognitive neuroscience of true and false memories. In R. F. Belli (Ed.), *Nebraska Symposium on Motivation: Vol. 58. True and false recovered memories: Toward a reconciliation of the debate* (pp. 15–52). New York: Springer.

Kuhl, B. A., Johnson, M. K., & Chun, M. M. (2013). Dissociable neural mechanisms for goal-directed versus incidental memory reactivation. *Journal of Neuroscience, 33,* 16099–16109.

Mitchell, K. J., & Johnson, M. K. (2009). Source monitoring 15 years later: What have we learned from fMRI about the neural mechanisms of source memory? *Psychological Bulletin, 135*, 638–677.

hemisphere for tasks requiring retrieval from semantic memory (Nyberg, Cabeza, & Tulving, 1996; Tulving et al., 1994). In contrast, there is more activation in the right prefrontal hemisphere for episodic retrieval tasks. This model, then, proposes that semantic and episodic memories must be distinct because they draw on separate areas of the brain. For example, if one is asked to generate verbs that are associated with nouns (e.g., *drive* with *car*), this task requires semantic memory. It results in greater left-hemispheric activation (Nyberg, Cabeza, & Tulving, 1996). In contrast, if people are asked to freely recall a list of words—an episodic-memory task—they show more right-hemispheric activation. Some recent functional magnetic resonance imaging (fMRI) and event-related potential studies have not found the predicted frontal asymmetries during encoding and retrieval (Berryhill et al., 2007; Evans & Federmeier, 2009).

Other findings suggest that the neural processes involved in these memories overlap (Rajah & McIntosh, 2005). Although there is substantial behavioral and neurological evidence that there are differences between these two types of memory, most researchers agree that, at the very least, a great deal of interaction occurs between these two types of memory. As a result, the question of whether these forms of memory are separate is still open.

A taxonomy of the memory system in terms of the dissociations described in the previous sections is shown in Figure 5.11 ■ (Squire, 1986, 1993). It distinguishes declarative (explicit) memory from various kinds of nondeclarative (implicit) memory. Nondeclarative memory includes procedural memory, priming effects, simple classical conditioning, habituation, sensitization, and perceptual aftereffects. In yet another view, there are five memory systems in all: episodic, semantic, perceptual (i.e., recognizing things on the basis of their form and structure), procedural, and working memory (Schacter, 2000).

A Connectionist Perspective

In addition to using laboratory experiments on human participants, cognitive psychologists have used computer models to simulate various aspects of information processing. The three-store model is based on serial (sequential) processing of information. Serial processing can be simulated on individual computers that handle only one operation at a time. Connectionist models argue, however, that our brain handles many operations and processes at once, so that a parallel-processing model of working memory (where multiple operations are processed at the same time) may make more sense. To continue our computer analogy, we would need multiple linked

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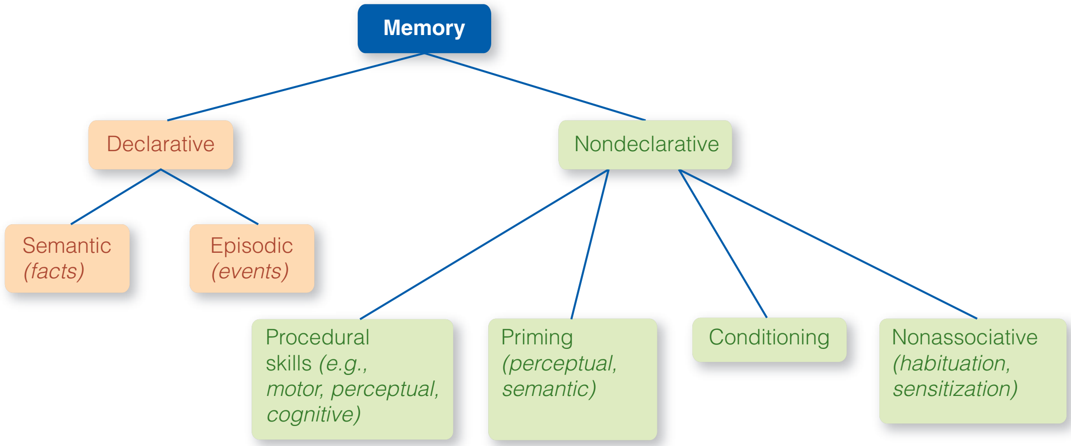

Memory
Declarative
Nondeclarative
Semantic (facts)
Episodic (events)
Procedural skills (e.g., motor, perceptual, cognitive)
Priming (perceptual, semantic)
Conditioning
Nonassociative (habituation, sensitization)

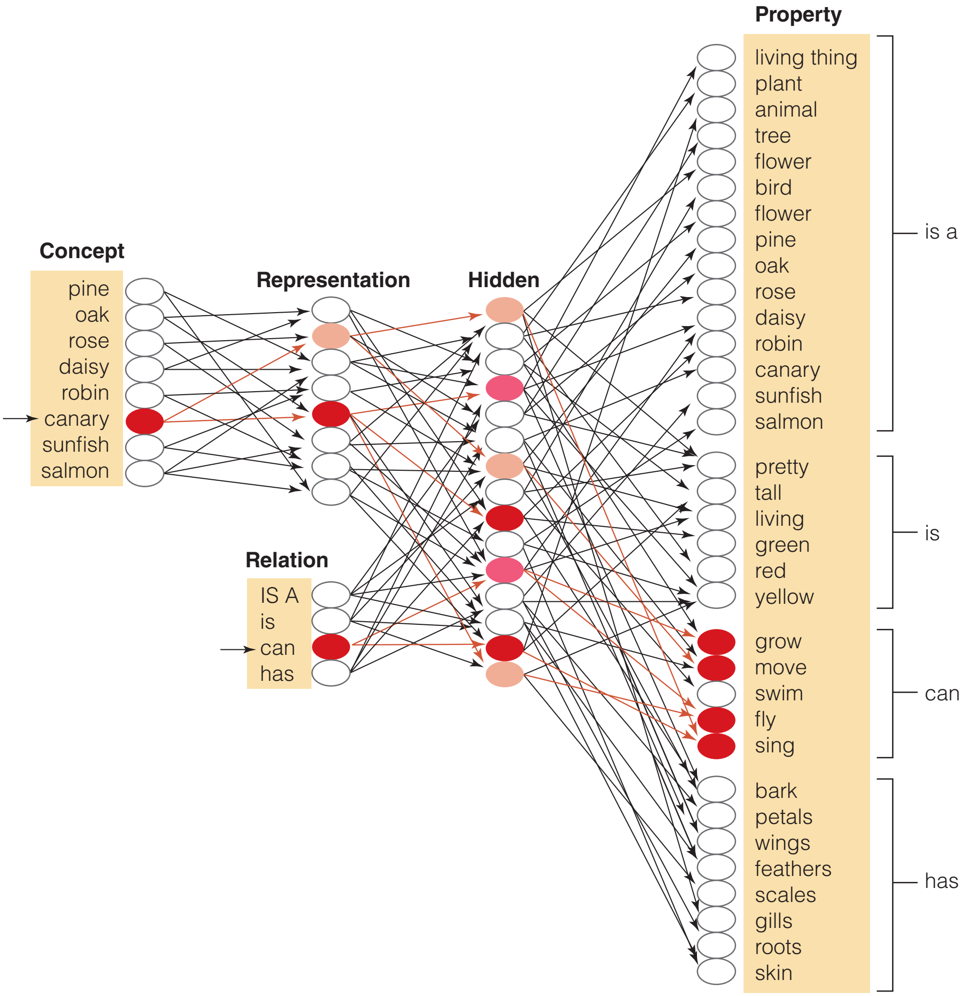
■ **Figure 5.11 A Taxonomy of the Memory System.** On the basis of extensive neuropsychological research, Larry Squire has posited that memory is made up of two fundamental types: declarative (explicit) memory and various forms of nondeclarative (implicit) memory, each of which may be associated with discrete cerebral structures and processes.

computers for parallel processing (or a single computer operating with parallel networks).

Many cognitive psychologists now prefer a parallel-processing model to describe many phenomena of memory. In addition to inspiring theoretical models of memory function, neuropsychological research has offered specific insights into memory processes. It also has provided evidence regarding various hypotheses of how human memory works.

The network model provides the structural basis for the *connectionist* parallel distributed-processing (PDP) model (see further description of this model in Chapter 8; Frean, 2003; Sun, 2003). The model is based on a network of interconnected neuron-like computational units (nodes). The key to knowledge representation lies in the connections among various *nodes*, or elements, stored in memory, not in each individual node (Feldman & Shastri, 2003). Activation of one node may prompt activation of a connected node. The strength of the received input depends both on the strength of the output signal from the sending unit and on the strength of the connection between the sending and receiving units. This process of spreading activation may prompt the activation of additional nodes (Figure 5.12 ■). Different patterns of activation represent different concepts. The PDP model fits nicely with the notion of working memory as including the activated portion of long-term memory. In this model, activation spreads through nodes within the network. This spreading continues as long as the activation does not exceed the limits of working memory.

The priming effect can be explained well with the PDP model. A **prime** is a node that activates a connected node. A **priming effect** is the resulting activation of the node. The priming effect has been supported by considerable evidence (see earlier examples, especially the studies of priming as an aspect of implicit memory). A widely used priming task is the word-completion task, in which some concepts that have been activated recently can be retrieved from memory with particular ease. In addition, some evidence supports the notion that priming is due to spreading activation (McClelland & Rumelhart, 1985, 1988). But not everyone agrees about the mechanism for the priming effect (see McKoon & Ratcliff, 1992b).


Concept
pine
oak
rose
daisy
robin
canary
sunfish
salmon
Representation
Hidden
Relation
IS A
is
can
has
Property
living thing
plant
animal
tree
flower
bird
flower
pine
oak
rose
daisy
robin
canary
sunfish
salmon
is a
pretty
tall
living
green
red
yellow
is
grow
move
swim
fly
sing
can
bark
petals
wings
feathers
scales
gills
roots
skin
has

■ **Figure 5.12** **Connectionist Network.** A connectionist network consists of many different nodes. Unlike in semantic networks, it is not a single node that has a specific meaning, but rather the knowledge is represented in a combination of differently activated nodes. The size of the dots inside the nodes above indicates the amount of activation (with larger dots indicating more activation). The concept of a canary is represented by the overall pattern of activation.
Source: Based on Goldstein, *Cognitive Psychology* 4e, Figure 9.18.

Connectionist models also have some intuitive appeal in their ability to integrate several contemporary notions about memory: Working memory includes the activated portion of long-term memory and operates through at least some amount of parallel processing. Spreading activation involves the simultaneous (parallel) activation (priming) of multiple links among nodes within the network. Many cognitive psychologists who hold this integrated view suggest that part of the reason we humans are as efficient as we are in processing information is that we can handle many operations at once. Thus, the contemporary cognitive-psychological conceptions of working memory, network models of memory, spreading activation, priming, and parallel processes mutually enhance and support one another.

Some of the research supporting this connectionist model of memory has come directly from experimental studies of people performing cognitive tasks in laboratory settings. Connectionist models effectively explain priming effects, skill learning (procedural memory), and several other phenomena of memory. Thus far, however, connectionist models have failed to provide clear predictions and explanations of recall and recognition memory that occurs following a single episode or a single exposure to semantic information.

Not all cognitive researchers accept the connectionist model. Some believe that human thought is more systematic and integrated than connectionist models seem to allow (Fodor & Pylyshyn, 1988; Matthews, 2003). They believe that complex behavior displays a degree of top-down orderliness and purposefulness that connectionist models, which are bottom-up, cannot incorporate. Connectionist modelers dispute this claim. The issue will be resolved as cognitive psychologists explore the extent to which connectionist models can reproduce and even explain complex behavior.

You might wonder why there are so many different models of memory (or perception or intelligence or whatever). In cognitive psychology, as in other sciences, we do not yet have all the answers. So scientists construct alternative models based on what they know. As they learn more, these models are either elaborated on or, ultimately, replaced. The fact that there are multiple models shows that we do not yet have a complete understanding of a phenomenon, but it also shows that scientists are actively investigating the phenomenon in search of the best possible future model, which is likely to share features in common with several existing models but to be identical to none of them.

CONCEPT CHECK

1. What is the difference between the sensory store and the short-term store?
2. What are levels of processing?
3. What are the components of the working-memory model?
4. Why do we need both semantic and episodic memories?
5. Describe a connectionist model of memory.

Exceptional Memory and Neuropsychology

Up to this point, the discussion of memory has focused on tasks and structures involving normally functioning memory. However, there are rare cases of people with exceptional memory (either enhanced or deficient) that provide some interesting insights into the nature of memory in general. The study of exceptional memory leads directly to neuropsychological investigations of the physiological mechanisms underlying memory.

Outstanding Memory: Mnemonists

Imagine what your life would be like if you were able to remember every word printed in this book. In this case, you would be considered a **mnemonist**, someone who demonstrates extraordinarily keen memory ability, usually based on using special techniques for memory enhancement. Perhaps the most famous of mnemonists was a man called "S."

Russian psychologist Alexander Luria (1968) reported that one day S. appeared in his laboratory and asked to have his memory tested. Luria tested him. He discovered that the man's memory appeared to have virtually no limits. S. could reproduce extremely long strings of words, regardless of how much time had passed since the words had been presented to him. Luria studied S. for more than 30 years. He found that even when S.'s retention was measured 15 or 16 years after a session in which S. had learned words, S. still could reproduce the words. S. eventually became a professional entertainer. He dazzled audiences with his ability to recall whatever was asked of him.

What was S.'s trick? How did he remember so much? Apparently, he relied heavily on the mnemonic of visual imagery. He converted material that he needed to remember into visual images. For example, he reported that when asked to remember the word *green,* he would visualize a green flowerpot. For the word *red,* he visualized a man in a red shirt coming toward him. Numbers called up images. For example, *1* was a proud, well-built man. The number *3* was a gloomy person. The number *6* was a man with a swollen foot, and so on.

For S., much of his use of visual imagery in memory recall was not intentional. Rather, it was the result of a rare psychological phenomenon. This phenomenon, termed *synesthesia,* is the experience of sensations in a sensory modality different from the sense that has been physically stimulated. For example, S. automatically would convert a sound into a visual impression. He even reported experiencing a word's taste and weight. Each word to be remembered evoked a whole range of sensations that automatically would come to S. when he needed to recall that word.

Other mnemonists have used different strategies. "V. P.," a Russian immigrant, could memorize long strings of material, such as rows and columns of numbers (Hunt & Love, 1972). Whereas S. relied primarily on visual imagery, V. P. apparently relied more on verbal translations. He reported memorizing numbers by transforming them into dates. Then he would think about what he had done on that day.

Another mnemonist, "S. F.," remembered long strings of numbers by segmenting them into groups of three or four digits each. He then encoded them into running times for different races (Ericsson, Chase, & Faloon, 1980). An experienced long-distance runner, S. F. was familiar with the times that would be plausible for different races. S. F. did not enter the laboratory as a mnemonist. Rather, he had been selected to represent the average college student in terms of intelligence and memory ability.

S. F.'s original memory for a string of numbers was about seven digits, average for a college student. After 200 practice sessions distributed over a period of 2 years, however, S. F. had increased his memory for digits more than tenfold. He could recall up to about 80 digits. His memory was impaired severely, however, when the experimenters purposely gave him sequences of digits that could not be translated into running times. The work with S. F. suggests that a person with a fairly typical level of memory ability can, at least in principle, be converted into one with quite an extraordinary memory. At least, this is possible in some domains, following a great deal of concerted practice.

Many of us yearn to have memory abilities like those of S. or V. P. In this way, we may believe we could ace our exams virtually effortlessly. We should consider, however, that S. was not particularly happy with his life, and part of the reason was his exceptional memory. He reported that his synesthesia, which was largely involuntary, interfered with his ability to listen to people. Voices gave rise to blurs of sensations. They in turn interfered with his ability to follow a conversation. Moreover, S.'s heavy reliance on imagery created difficulty for him when he tried to understand abstract concepts. For example, he found it hard to understand concepts such as *infinity* or *nothing.* These concepts do not lend themselves well to visual images. He also sometimes was overwhelmed when he read. Earlier memories also sometimes intruded on later ones. Of course, we cannot say how many of S.'s problems in life were caused by his exceptional memory. But clearly S. believed that his exceptional memory had a downside as well as an upside. It was often as likely to be a hindrance as a help.

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These exceptional mnemonists offer some insight into processes of memory. Each of the three described here did more or less the same thing—consciously or almost automatically. Each translated arbitrary, abstract, meaningless information into more meaningful and often more concrete information, sometimes connected to the senses. Whether the translated information was horseracing times, dates and events, or visual images, the key was their meaning for the mnemonist.

Like the mnemonists, we more easily encode information into our long-term memory that is similar to the information already stored there. Because we have information in long-term memory that pertains to our interests, it is easier to learn new information that is in line with these interests that we can relate to the old information (De Beni et al., 2007). Thus, you may be able to remember the lyrics of your favorite songs from years ago but not be able to recall the definitions of new terms that you have just learned. You can improve your memory for new information if you can relate the new information to old information already stored in long-term memory.

If you are unable to retrieve a memory that you need, does it mean that you have forgotten it? Not necessarily. Cognitive psychologists have studied a phenomenon called **hypermnesia**, which is a process of producing retrieval of memories that would seem to have been forgotten (Erdelyi & Goldberg, 1979; Holmes, 1991; Turtle & Yuille, 1994). Hypermnesia is sometimes loosely referred to as "unforgetting," although the terminology cannot be correct because, strictly speaking, the memories that are retrieved were never unavailable (i.e., forgotten), but rather, they were inaccessible (i.e., hard to retrieve). Hypermnesia is usually achieved by trying many and diverse retrieval cues to unearth a memory. Psychodynamic therapy, for example, is sometimes used to try to achieve hypermnesia. This therapy also points out the risk of trying to achieve hypermnesia. The individual may create a new memory, believing it is an old one, rather than retrieving a genuine old memory. In cases in which there are accusations of abuse against a parent or other individual, newly created memories posing as old memories could pose a serious problem leading to false accusations.

We usually take for granted the ability to remember, much like the air we breathe. However, just as we become more aware of the importance of air when we do not have enough to breathe, we are less likely to take memory for granted when we observe people with serious memory deficiencies.

Deficient Memory

Many syndromes are associated with memory loss. Just as with the study of exceptionally good memory, the study of deficient memory provides us with many valuable insights into how memory works. In this section, we will have a look at two syndromes. The first and also most well known is amnesia. Afterward, we will explore the symptoms and causes of Alzheimer's disease, which is another prominent disease that causes memory loss.

Amnesia

We begin this section on amnesia by looking at some case studies to gain a better understanding of what amnesia is and what different kinds of amnesia exist. Afterward, we will consider what insights can be gained about the differences between implicit and explicit memory by studying amnesia, and have a look at neuropsychological findings in the context of amnesia.

What Is Amnesia? **Amnesia** is severe loss of explicit memory (Robbins, 2009). One type is **retrograde amnesia**, in which individuals lose their purposeful memory for events before whatever trauma induces memory loss (Levine et al., 2009; Squire, 1999).

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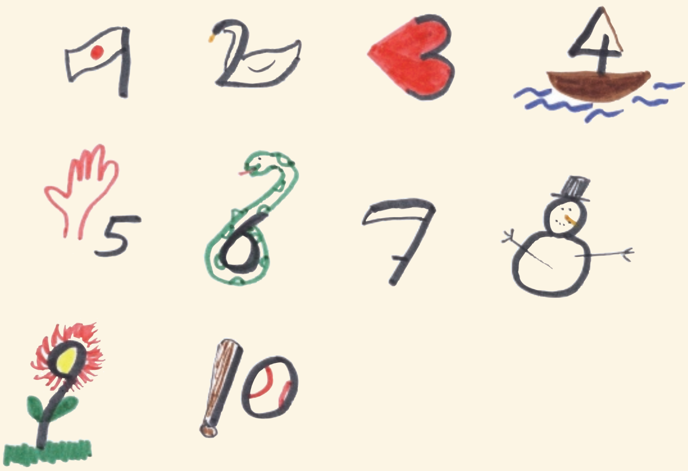
BELIEVE IT OR NOT | You Can Be a Memory Champion, Too!

Have you ever heard about people who can effortlessly remember huge lists of words or numbers? Or would you already be satisfied if you could memorize your shopping list? Well, you can do this, too! How? The first thing you need to do is to come up with a nice system that helps you remember numbers. Then you connect the words you want to remember with those numbers. Sounds too complicated? Not really. The following example illustrates how you can imagine numbers as representations of objects (remember, you can create your own system).

Once you are intimately familiar with your representations of numbers, you can start connecting them with words you would like to remember. Assume you want to buy beans, chopped tomatoes, and cereal. You'll create lively pictures that combine the numbers with the items you need to buy. For the first item, you can imagine beans growing up high on a flagpole, for example. For the second item, you can imagine a swan with red plumage because it is swimming in a pond of chopped tomatoes. And for the third item, you can imagine a nice plate of breakfast cereal shaped in the form of hearts. You get the idea? Once you are in the supermarket, you'll just work down your list from the first item to the last, imagining your created pictures. There are no rules except that the representations have to work for you. With a little bit of practice you'll soon be able to memorize long lists of words, even more complicated or abstract ones. This technique is one of many mnemonic techniques that belong to the group of association techniques.



Mnemonics

Courtesy of the author

Mild forms of retrograde amnesia can occur fairly commonly when someone sustains a concussion. Usually, events immediately before the concussive episode are not well remembered.

W. Ritchie Russell and P. W. Nathan (1946) reported a more severe case of retrograde amnesia. A 22-year-old landscaper was thrown from his motorcycle in August of 1933. A week after the accident, the young man was able to converse sensibly. He seemed to have recovered. However, it quickly became apparent that he had suffered a severe loss of memory for events that had occurred before the trauma. On questioning, he gave the date as February 1922. He believed himself to be a schoolboy. He had no recollection of the intervening years. Over the next several weeks, his memory for past events gradually returned. The return started with the least recent event and proceeded toward more recent events. By 10 weeks after the accident, he had recovered

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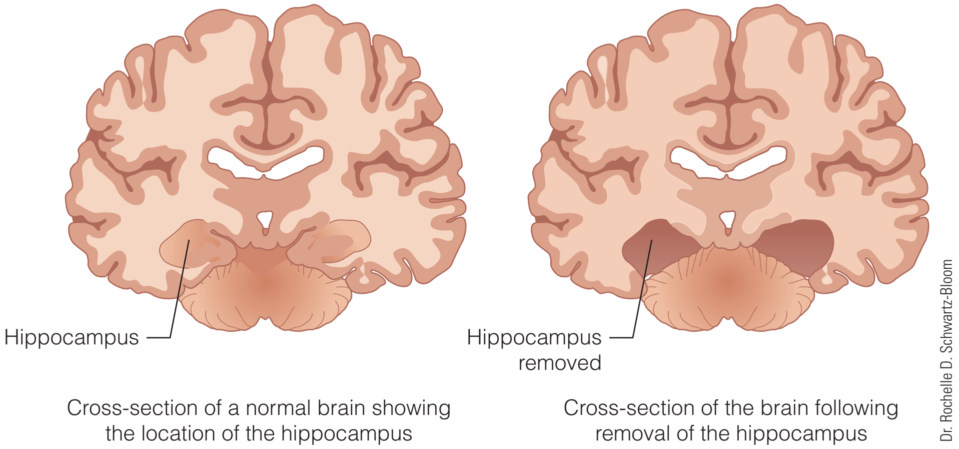
Hippocampus
Hippocampus removed
Cross-section of a normal brain showing the location of the hippocampus
Cross-section of the brain following removal of the hippocampus

Dr. Rochelle D. Schwartz-Bloom

A view of a normal brain and H. M.'s brain (with the hippocampus removed).

his memory for most of the events of the previous years. He finally was able to recall everything that had happened up to a few minutes before the accident. In retrograde amnesia, the memories that return typically do so starting from the more distant past. They then progressively return up to the time of the trauma. Often events right before the trauma are never recalled.

One of the most famous cases of amnesia is the case of H. M. (Scoville & Milner, 1957). H. M. underwent brain surgery to save him from continual disruptions resulting from uncontrollable epilepsy. The operation took place on September 1, 1953. It was largely experimental. The results were highly unpredictable. At the time of the operation, H. M. was 29 years old. He was above average in intelligence. After the operation, his recovery was uneventful with one exception. He suffered severe **anterograde amnesia**, the inability to remember events that occur after a traumatic event. Although he had good (although not perfect) recollection of events that had occurred before his operation, H. M.'s memory loss severely affected his life. H. M. was extensively studied through behavioral and neurological methods. On one occasion, he remarked, "Every day is alone in itself, whatever enjoyment I've had, and whatever sorrow I've had" (Milner, Corkin, & Teuber, 1968, p. 217). Many years after the surgery, H. M. still reported that the year was 1953. He also could not recall the name of any new person he met after the operation, regardless of the number of times they interacted. Apparently, H. M. lost his ability to recollect any new memories of the time following his operation. As a result, he lived suspended in an eternal present.

The examination of H. M.'s memory continued for most of his life, with later work examining changes in H. M.'s memory and brain as he aged. Before his death in 2008 (at age 82), studies noted additional memory and cognitive declines. In particular, H. M. exhibited new problems with comprehension and generation of new sentences (MacKay, 2006; MacKay et al., 2006; Salat et al., 2006; Skotko et al., 2004).

Another kind of "amnesia" that we all experience is **infantile amnesia**, the inability to recall events that happened when we were very young (Spear, 1979). (We place amnesia in quotation marks because some investigators question whether infantile amnesia is truly a form of amnesia at all.)

Amnesia and the Explicit-Implicit Memory Distinction Why do researchers study amnesia patients? What kinds of insight can be gained from amnesia research?

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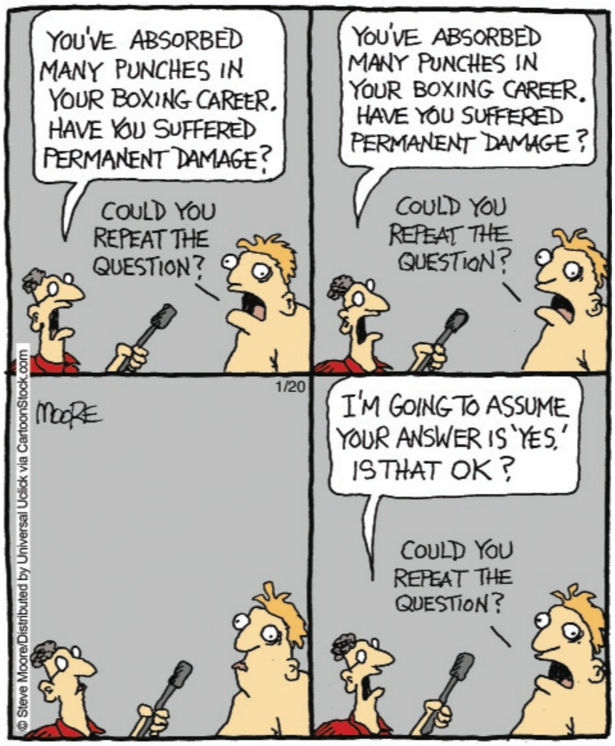
One of the general insights gained by studying amnesia victims highlights the distinction between explicit and implicit memories. Explicit memory is typically impaired in amnesia. Implicit memory, such as priming effects on word-completion tasks and procedural memory for skill-based tasks, is typically not impaired. This observation indicates that two kinds of abilities need to be distinguished. The first is the ability to reflect consciously on prior experience, which is required for tasks involving explicit memory. The second is the ability to demonstrate remembered learning in an apparently automatic way, without conscious recollection of the learning (implicit memory; Baddeley, 1989). Priming effects can be seen from about 250 to 500 milliseconds after exposure through positive brain potentials recorded in the frontal region of the brain. Explicit memory retrieval, however, is indicated by brain potentials that appear at a later time in the posterior regions (Voss & Paller, 2006).

Amnesia victims perform extremely poorly on most explicit memory tasks, but they may show normal or almost-normal performance on tasks involving implicit memory, such as cued-recall tasks (Warrington & Weiskrantz, 1970) and word-completion tasks (Baddeley, 1989). What do you think happens after word-completion tasks? When amnesics were asked whether they previously had seen the word they just completed, they were unlikely to remember the specific experience of having seen the word (Graf, Mandler, & Haden, 1982; Tulving, Schacter, & Stark, 1982). Furthermore, these amnesics do not explicitly recognize words they have seen at better than chance levels. Although the distinction between implicit memory and explicit memory has been observed readily in amnesics, both amnesics and normal participants show the presence of implicit memory.

Likewise, amnesia victims also show paradoxical performance in another regard. Consider two kinds of tasks. As previously described, *procedural-knowledge* tasks involve "knowing how." They involve skills such as how to ride a bicycle, whereas *declarative-knowledge* tasks involve "knowing that." They tap factual information, such as the terms in a psychology textbook. On the one hand, amnesia victims may perform extremely poorly on the traditional memory tasks requiring recall or recognition memory of declarative knowledge. On the other hand, they may demonstrate improvement in performance resulting from learning—remembered practice—when engaged in tasks that require procedural knowledge. Such tasks would include solving puzzles, learning to read mirror writing, or mastering motor skills (Baddeley, 1989).

Consider an example of procedural knowledge that is retained when a person suffers from amnesia. Patients with amnesia, when asked to drive in a normal situation, were able to operate and control the car as a normal driver would (Anderson et al., 2007). The investigators, however, also exposed the patients to a simulation in which they had to make a fast decision to avoid an accident. In this situation, the patients with amnesia showed significant impairment. They could not recall the proper response to this situation. This finding is in line with the fact that in patients with amnesia, implicit, procedural knowledge is spared, whereas explicit knowledge is impaired. Most drivers do not have extensive experience with complex accident-avoidance scenarios and therefore would have to rely more on their declarative memory to make decisions about how to respond.

Amnesia and Neuropsychology Studies of amnesia victims have revealed much about the way in which memory depends on the effective functioning of particular structures of the brain. By looking for matches between particular lesions in the brain and particular deficits of function, researchers come to understand how normal memory functions. Thus, when studying cognitive processes in the brain, neuropsychologists frequently look for dissociations of function. In *dissociations,* normal individuals show the presence of a particular function (e.g., explicit memory). But people


YOU'VE ABSORBED MANY PUNCHES IN YOUR BOXING CAREER. HAVE YOU SUFFERED PERMANENT DAMAGE?
COULD YOU REPEAT THE QUESTION?
YOU'VE ABSORBED MANY PUNCHES IN YOUR BOXING CAREER. HAVE YOU SUFFERED PERMANENT DAMAGE?
COULD YOU REPEAT THE QUESTION?
MOORE
1/20
I'M GOING TO ASSUME YOUR ANSWER IS 'YES.' IS THAT OK?
COULD YOU REPEAT THE QUESTION?
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with specific lesions in the brain show the absence of that particular function. This absence occurs despite the presence of normal functions in other areas (e.g., implicit memory).

By observing people with disturbed memory function, we know that memory is volatile. A blow to the head, a disturbance in consciousness, or any number of other injuries to or diseases of the brain may affect it. We cannot determine, however, the specific cause–effect relationship between a given structural lesion and a particular memory deficit. The fact that a particular structure or region is associated with an interruption of function does not mean that the region is solely responsible for controlling that function. Indeed, functions can be shared by multiple structures or regions. A broad physiological analogy may help to explain the difficulty of determining localization based on an observed deficit. The normal functioning of a portion of the brain—the reticular activating system (RAS)—is essential to life. But life depends on more than a functioning brain. If you doubt the importance of other structures, ask a patient with heart or lung disease. Thus, although the RAS is essential to life, a person's death may be the result of malfunction in other structures of the body. Tracing a dysfunction within the brain to a particular structure or region poses a similar problem.

For the observation of simple dissociations, many alternative hypotheses may explain a link between a particular lesion and a particular deficit of function. Much more compelling support for hypotheses about cognitive functions comes from observing double dissociations. In *double dissociations,* people with different kinds of neuropathological conditions show opposite patterns of deficits. A double dissociation can be observed if a lesion in brain structure *1* leads to impairment in memory function *A* but not in memory function *B*; and a lesion in brain structure *2* leads to impairment in memory function *B* but not in memory function *A*.

For some functions and some areas of the brain, neuropsychologists have managed to observe the presence of a double dissociation. For example, some evidence for distinguishing brief memory from long-term memory comes from just such a double dissociation (Schacter, 1989b). People with lesions in the left parietal lobe of the brain show profound inability to retain information in short-term memory, but they show no impairment of long-term memory. They continue to encode, store, and retrieve information in long-term memory, apparently with little difficulty (Shallice & Warrington, 1970; Warrington & Shallice, 1972). In contrast, people with lesions in the medial (middle) temporal regions of the brain show relatively normal short-term memory of verbal materials, such as letters and words, but they show serious inability to retain new verbal materials in long-term memory (Milner, Corkin, & Teuber, 1968; Shallice, 1979; Warrington, 1982).

Double dissociations offer strong support for the notion that particular structures of the brain play particular vital roles in memory (Squire, 1987). Disturbances or lesions in these areas cause severe deficits in memory formation. But we cannot say that memory—or even part of memory—resides in these structures. Nonetheless, studies of brain-injured patients are informative and at least suggestive of how memory works.

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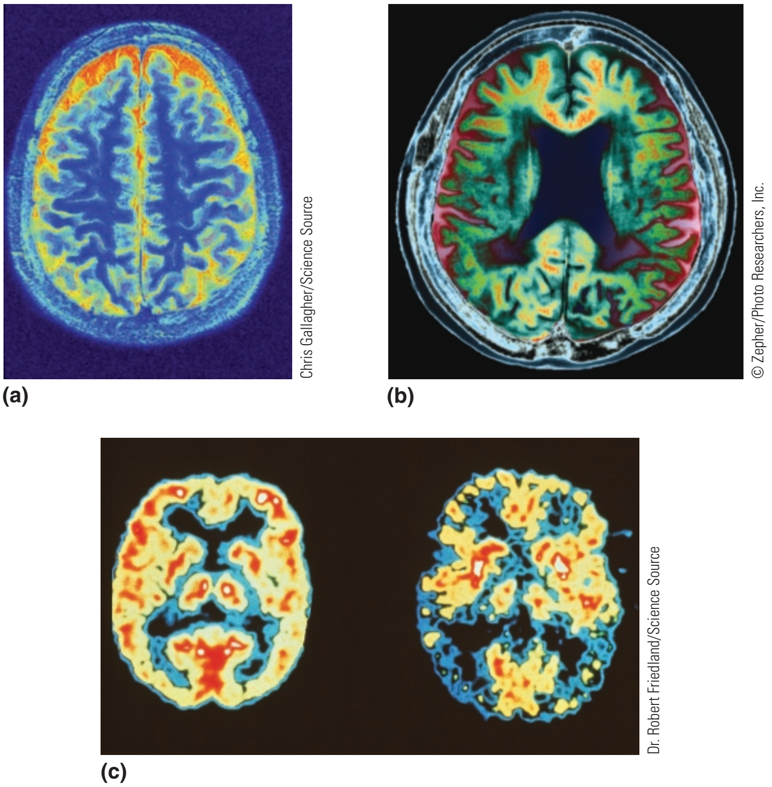
At present, cognitive neuropsychologists have found that double dissociations support several distinctions. These distinctions are those between brief memory and long-term memory and between declarative (explicit) and nondeclarative (implicit) memory. There also are some preliminary indications of other distinctions.

Alzheimer's Disease

Although amnesia is the syndrome most associated with memory loss, it is often less devastating than a disease that includes memory loss as one of many symptoms. **Alzheimer's disease** is a disease of older adults that causes dementia as well as progressive memory loss (Kraus, 2014). Dementia is a loss of intellectual function that is severe enough to impair one's everyday life. The memory loss in Alzheimer's disease can be seen in comparative brain scans of individuals with and without Alzheimer's disease. Note in Figure 5.13 ■ that as the disease advances, there is diminishing cognitive activity in the areas of the brain associated with memory function.

The disease was first identified by Alois Alzheimer in 1907. It is typically recognized on the basis of loss of intellectual function in daily life. Formally, a definitive diagnosis is possible only after death. Alzheimer's disease leads to an atrophy (decrease in size) of the brain; especially in the hippocampus and frontal and temporal brain regions (Jack et al.,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■ **Figure 5.13 The Brain with and without Alzheimer's Disease.** Brain scans of (a) a normal individual and (b) an individual with early-stage Alzheimer's. You can see the atrophy (black space) in the brain of the Alzheimer's patient (b) compared with the healthy person (a). Image (c) depicts PET scans of an individual with late-stage Alzheimer's disease and a healthy person. The metabolism in the healthy brain is much more pronounced. As the disease progresses, cognitive activity in the brain associated with memory function decreases.

2002; Stěpán-Buksakowska et al., 2014). The brains of people with the disease show plaques and tangles that are not found in normal brains. Plaques are dense protein deposits found outside the nerve cells of the brain (Mirochnic et al., 2009). Tangles are pairs of filaments that become twisted around each other. They are found in the cell body and dendrites of neurons and often are shaped like a flame (Kensinger & Corkin, 2003). Alzheimer's disease is diagnosed when memory is impaired and there is at least one other area of dysfunction in the domains of language, motor, attention, executive function, personality, or object recognition. The symptoms are of gradual onset, and the progression is continuous and irreversible.

Although the progression of disease is irreversible, it can be slowed somewhat. The main drug currently being used for this purpose is Donepezil (Aricept). Research evidence is mixed (Fischman, 2004). It suggests that, at best, Aricept may slightly slow progression of the disease, but it cannot reverse it. A more recent drug, memantine (sold as Namenda or Ebixa), can supplement Aricept and slow progression of the disease somewhat more. The two drugs have different mechanisms. Aricept slows destruction of the neurotransmitter acetylcholine in the brain. Memantine inhibits a chemical that overexcites brain cells and leads to cell damage and death (Fischman, 2004).

The incidence of Alzheimer's increases exponentially with age (Alzheimer's Association, 2014). About 1% of people between 70 and 75 years of age experience an onset of Alzheimer's disease. But between ages 80 and 85 years, the incidence is more than 6% a year.

A special kind of Alzheimer's disease is familial, known as early-onset Alzheimer's disease. It has been linked to a genetic mutation. People with the genetic mutation always develop the disease. It results in the disease exhibiting itself early, often before even 50 years of age and sometimes as early as the 20s (Kensinger & Corkin, 2003). Late-onset Alzheimer's disease, in contrast, appears to be complexly determined and related to a variety of possible genetic and environmental influences, none of which have been conclusively identified.

The earliest signs of Alzheimer's disease typically include impairment of episodic memory. People have trouble remembering things that were learned in a temporal or spatial context. As the disease progresses, semantic memory also begins to go. Whereas people without the disease tend to remember emotionally charged information better than they remember nonemotionally charged information, people with the disease show no difference in the two kinds of memory (Kensinger et al., 2002). Most forms of nondeclarative memory are spared in Alzheimer's disease until near the very end of its course. The end is inevitably death, unless the individual dies first of other causes.

Memory tests may be given to assess whether an individual has Alzheimer's disease. Definitive diagnosis, however, is possible only through analysis of brain tissue, which, as mentioned earlier, shows plaques and tangles in cases of disease. In one test, individuals see a sheet of paper containing four words (Buschke et al., 1999). Each word belongs to a different category. The examiner says the category name for one of the words. The individual must point to the appropriate word. For example, if the category is animal, the individual might point to a picture of a cow. A few minutes after the words have been presented, individuals make an attempt to recall all the words they saw. If they cannot recall a word, they are given the category to which the word belongs. Some individuals cannot remember the words, even when prompted with the categories. Alzheimer's patients score much worse on this test than do other individuals.

CONCEPT CHECK

1. Define amnesia and name three forms of amnesia.
2. What is Alzheimer's disease?

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Key Themes

This chapter illustrates some of the key themes noted in Chapter 1.

Applied versus basic research. Basic and applied research can interact. An example is research on Alzheimer's disease. Presently, the disease is not curable, but is treatable with drugs and with guidance provided in a structured living environment. Basic research into the biological structures (e.g., tangles and plaques) and cognitive functions (e.g., impaired memory) associated with Alzheimer's may one day help us better understand and treat the disease.

Biology versus behavioral methods. This chapter shows the interaction of biology with behavior. The hippocampus has become one of the most carefully studied parts of the brain. Current fMRI research is showing how the hippocampus and other parts of the brain, such as the amygdala (in the case of emotionally based memories) and the cerebellum (in the case of procedural memories), function to enable us to remember what we need to know. Biological processes have an impact on what we experience, how we behave, and what we remember.

Structures versus processes. Structure and function are both important to understanding human memory. The Atkinson–Shiffrin model proposed control processes that operate on three structures: a very short-term store, a short-term store, and a long-term store. The more recent working-memory model proposes how executive function controls and activates portions of long-term memory to provide the information needed to solve tasks at hand.

SUMMARY

1. **What are some of the tasks used for studying memory, and what do various tasks indicate about the structure of memory?** Among the many tasks used by cognitive psychologists, some of the main ones have been tasks assessing explicit recall of information (e.g., free recall, serial recall, and cued recall) and tasks assessing explicit recognition of information. By comparing memory performance on these explicit tasks with performance on implicit tasks (e.g., word-completion tasks), cognitive psychologists have found evidence of differing memory systems or processes governing each type of task (e.g., as shown in studies of amnesics).
2. **What has been the prevailing traditional model for the structure of memory?** Memory is the means by which we draw on our knowledge of the past to use this knowledge in the present. According to one model, memory is conceived as involving three stores: A sensory store is capable of holding relatively limited amounts of information for very brief periods; a short-term store is capable of holding small amounts of information for somewhat longer periods; and a long-term store is capable of storing large amounts of information virtually indefinitely. Within the sensory store, the iconic store refers to visual sensory memory.
3. **What are some of the main alternative models for the structure of memory?** An alternative model uses the concept of working memory, usually defined as being part of long-term memory and also comprising short-term memory. From this perspective, working memory holds only the most recently activated portion of long-term memory. It moves these activated elements into and out of short-term memory.

A second model is the levels-of-processing framework, which hypothesizes distinctions in memory ability based on the degree to which items are elaborated during encoding.

A third model is the multiple memory systems model, which posits not only a distinction between procedural memory and declarative (semantic) memory but also a distinction between semantic and episodic memory.

In addition, psychologists have proposed other models for the structure of memory. They include a parallel-distributed processing (PDP; connectionist) model. The PDP model incorporates the notions of working memory, semantic memory networks, spreading activation, priming, and parallel processing of information.

Finally, many psychologists call for a complete change in the conceptualization of memory, focusing on memory functioning in the real world. This call leads to a shift in memory metaphors from the traditional storehouse to the more modern correspondence metaphor.

4. **What have psychologists learned about the structure of memory by studying exceptional memory and the physiology of the brain?** Among other findings, studies of mnemonists have shown the value of imagery in memory for concrete information. They also have demonstrated the importance of finding or forming meaningful connections among items to be remembered. The main forms of amnesia are anterograde amnesia, retrograde amnesia, and infantile amnesia. The last form of amnesia is qualitatively different from the other forms and occurs in everyone.

Through the study of the memory function of people with each form of amnesia, it has been possible to differentiate various aspects of memory. These include long-term versus temporary forms of memory, procedural versus declarative memory processes, and explicit versus implicit memory.

Although specific memory traces have not yet been identified, many of the specific structures involved in memory function have been located. To date, the subcortical structures involved in memory appear to include the hippocampus, the thalamus, the hypothalamus, and even the basal ganglia, and the cerebellum. The cortex also governs much of the long-term storage of declarative knowledge.

The neurotransmitters serotonin and acetylcholine appear to be vital to memory function. Other physiological chemicals, structures, and processes also play important roles, although further investigation is required to identify these roles.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe two characteristics each of sensory memory, short-term memory, and long-term memory.
2. What are double dissociations, and why are they valuable to understanding the relationship between cognitive function and the brain?
3. Compare and contrast the three-store model of memory with one of the alternative models of memory.
4. Critique one of the experiments described in this chapter (e.g., Sperling's 1960 experiment on the iconic store, or Craik and Tulving's 1975 experiment on the levels-of-processing model). What problem do you see regarding the interpretation given? How could subsequent research be designed to enhance the interpretation of the findings?

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5. How would you design an experiment to study some aspect of implicit memory?
6. Imagine what it would be like to recover from one of the forms of amnesia. Describe your impressions of and reactions to your newly recovered memory abilities.
7. How would your life be different if you could greatly enhance your own mnemonic skills in some way?

KEY TERMS

Alzheimer's disease, p. 197
amnesia, p. 192
anterograde amnesia, p. 194
central executive, p. 179
episodic buffer, p. 179
episodic memory, p. 185
explicit memory, p. 164
hypermnesia, p. 192
hypothetical constructs, p. 167
iconic store, p. 167
implicit memory, p. 164
infantile amnesia, p. 194
levels-of-processing (LOP) framework, p. 173
long-term store, p. 167
memory, p. 161
mnemonist, p. 190
phonological loop, p. 178
prime, p. 188
priming effect, p. 188
recall, p. 161
recognition, p. 161
retrograde amnesia, p. 192
semantic memory, p. 185
sensory store, p. 166
short-term store, p. 166
visuospatial sketchpad, p. 177
working memory, p. 176

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 24—Memory Span
Lab 18—Partial Report
Lab 45—Absolute Identification
Lab 25—Operation Span
Lab 46—Implicit Learning
Lab 17—Modality Effect
Lab 21—Position Error Effect
Lab 23—Irrelevant Speech Effect
Lab 26—Phonological Similarity Effect
Lab 29—Levels of Processing

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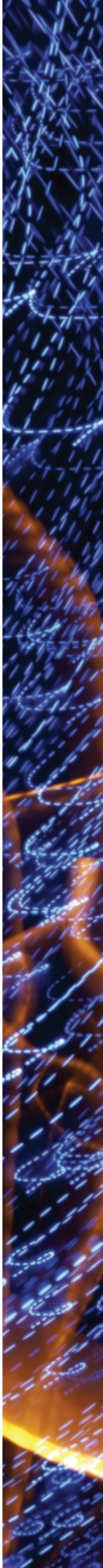
6

Memory Processes

CHAPTER OUTLINE

- **Encoding and Transfer of Information**
  - Forms of Encoding
    - Short-Term Storage
    - Long-Term Storage
  - Transfer of Information from Short-Term Memory to Long-Term Memory
    - Rehearsal
    - Organization of Information
- **Retrieval**
  - Retrieval from Short-Term Memory
    - Parallel or Serial Processing?
    - Exhaustive or Self-Terminating Processing?
    - The Winner—a Serial Exhaustive Model—with Some Qualifications
  - Retrieval from Long-Term Memory
- **Processes of Forgetting and Memory Distortion**
  - Interference Theory
  - Decay Theory
- **The Constructive Nature of Memory**
  - Autobiographical Memory
  - Memory Distortions
    - The Eyewitness Testimony Paradigm
    - Repressed Memories
  - The Effect of Context on Memory
- **Key Themes**
- **Summary**
- **Thinking about Thinking: Analytical, Creative, and Practical Questions**
- **Key Terms**
- **Media Resources**

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. What have cognitive psychologists discovered regarding how we encode information for storing it in memory?
2. What affects our ability to retrieve information from memory?
3. How does what we know or what we learn affect what we remember?

BELIEVE IT OR NOT

There's a Reason You Remember Those Annoying Songs

Having a song or part of a song stuck in your head is incredibly frustrating. We've all had the experience of the song from a commercial repeatedly running through our minds, even though we wanted to forget it. But sequence recall—remembering episodes or information in sequential order (like the notes to a song)—has a special and useful place in memory. We constantly have to remember sequences, from the movements involved in signing our name or making coffee in the morning, to the names of the exits that come before the motorway turn-off we take to drive home every day.

The ability to recall these sequences makes many aspects of everyday life possible. As you think about a snippet of song or speech, your brain may repeat a sequence that strengthens the connections associated with that phrase. In turn, this increases the likelihood that you will recall it, which leads to more reinforcement.

You could break this unending cycle of repeated recall and reinforcement—even though this is a necessary and normal process for the strengthening and cementing of memories—by introducing other sequences. Thinking of another song may allow a competing memory to crowd out the first one: Find another infectious song and hope that the cure doesn't become more annoying than the original problem.

In this chapter, we will learn more about how we store and recall information, as well as what makes us forget that information again.

Researchers John Bransford and Marcia Johnson (1972, p. 722) gave their participants the following procedure to follow. Are you able to recall the steps outlined in this procedure?

> *The procedure is actually quite simple. First, you arrange items into different groups. Of course one pile may be sufficient, depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step; otherwise, you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise. A mistake can be expensive as well. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then, one can never tell. After the procedure is completed one arranges the materials into different groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However, that is part of life.*

How easy or difficult is it for you to remember all the details? Bransford and Johnson's participants (and probably you, too) had a great deal of difficulty understanding this passage and recalling the steps involved. What makes this task so difficult? What are the mental processes involved in this task?

As mentioned in the previous chapter, cognitive psychologists generally organize the main processes of memory according to three common operations: encoding, storage, and retrieval. Each one represents a stage in memory processing:

- **Encoding** refers to how you transform a physical, sensory input into a representation that can be placed into memory.
- **Storage** refers to how you store (keep) encoded information in memory.
- **Retrieval** refers to how you gain access to information stored in memory.

Our emphasis in discussing these processes will be on recall of verbal and pictorial material. Remember, however, that we have memories of other kinds of stimuli as well, such as odors (Herz & Engen, 1996; Olsson et al., 2009).

Encoding, storage, and retrieval often are viewed as sequential stages. You first take in information. Then you hold it for a while. Later you pull it out. The processes, however, interact with each other and are interdependent. For example, you may have found the Bransford and Johnson procedure difficult to encode, thereby also making it hard to store and to retrieve the information. A verbal label, however, can facilitate encoding and hence storage and retrieval.

Most people do much better with the passage if given its title, "Washing Clothes." Now, read the procedure again. Can you recall the steps described in the passage? The verbal label, "washing clothes," helps us to encode and therefore to remember a passage that otherwise seems incomprehensible.

Encoding and Transfer of Information

Before information can be stored in memory, it first needs to be encoded for storage. Even if the information is held in our short-term memory, it is not always transferred to our long-term memory. So, to remember events and facts over a long period of time, we need to encode and subsequently transfer them from short-term to long-term storage. We will explore these processes in the forthcoming section.

Forms of Encoding

We encode our memories to store them. But do short-term and long-term storage use the same kind of code to store information, or do their codes differ? Let us have a look at some research to answer this question.

Short-Term Storage

When you encode information for temporary storage and use, what kind of code do you use? This is what Conrad (1964) set out to discover with an experiment. Participants were visually presented with several series of six letters at the rate of 0.75 seconds per letter. The letters used in the various lists were *B, C, F, M, N, P, S, T, V,* and *X*. No vowels were included to ensure that letter combinations did not result in any words or pronounceable combinations that could be memorized more easily. Immediately after the letters were presented, participants were asked to write down each list of six letters in the order given. What kinds of errors did participants make? Despite the fact that letters were presented visually, errors tended to be based on acoustic confusability. In other words, instead of recalling the letters they were supposed to recall, participants substituted letters that sounded like the correct letters. Thus, they were likely to confuse *F* for *S, B* for *V, P* for *B,* and so on.

Another group of participants simply listened to single letters in a setting that had noise in the background. They then immediately reported each letter as they heard it. Participants showed the same pattern of confusability in the listening task as in the visual memory task (Conrad, 1964). Thus, we seem to encode visually presented letters by how they sound, not by how they look.

For short-term memory, an acoustic code is more important than a visual code, as shown in the Conrad experiment. But the results do not rule out the possibility that other codes exist. One such code would be a *semantic code*—one based on word meaning.

Baddeley (1966) argued that short-term memory relies primarily on an acoustic rather than a semantic code. He gave his participants lists of words to read and compared recall performance for lists of acoustically confusable words—such as *map, cab, mad, man,* and *cap*—with lists of acoustically distinct words—such as *cow, pit, day, rig,* and *bun.* He found that performance was much worse for the visual presentation of acoustically similar words, thus indicating that the acoustic code plays a significant role in encoding. He also compared performance for lists of semantically similar words—such as *big, long, large, wide,* and *broad*—with performance for lists of semantically dissimilar words—such as *old, foul, late, hot,* and *strong.* There was little difference in recall between the two lists. If performance for the semantically similar words had been much worse, what would such a finding have meant? It would have indicated that participants were confused by the semantic similarities and hence were processing the words semantically. Performance, however, for the semantically similar words was only *slightly* worse than that for the semantically dissimilar words, meaning that semantics did not matter much for processing.

Subsequent work investigating how information is encoded in short-term memory has shown clear evidence, however, of at least some semantic encoding in short-term memory (Shulman, 1970; Wickens, Dalezman, & Eggemeier, 1976). Thus, encoding in short-term memory appears to be primarily acoustic, but there may be some secondary semantic encoding as well. In addition, we sometimes temporarily encode information visually as well (Posner, 1969; Posner et al., 1969; Posner & Keele, 1967). But visual encoding appears to be even more fleeting (about 1.5 seconds). We are more likely to forget visual information than acoustic information. Thus, initial encoding is primarily acoustic in nature, but other forms of encoding may be used under some circumstances. For example, when you remember a telephone number from long ago, you are more likely to remember how it sounds when you say it to yourself than to remember a visual image of the digits as written on a piece of paper.

Long-Term Storage

As mentioned, information stored temporarily in working memory is encoded primarily in acoustic form. So, when we make errors in retrieving words from short-term memory, the errors tend to reflect confusions in sound. How is information encoded into a form that can be transferred into storage and available for subsequent retrieval?

Most information stored in long-term memory primarily is encoded semantically. In other words, it is encoded by the meanings of words. Consider some relevant evidence.

Participants in a research study learned a list of 41 words (Grossman & Eagle, 1970). Five minutes after learning the list, participants were given a recognition test. Included in the recognition test were distracters—items that appear to be legitimate choices but that are not correct alternatives. Nine of the distracters (words that were not in the list of 41 words) were semantically related to words on the list. Nine were not. The researchers were interested in "false alarm" responses in which the participants indicated that they had seen the distracters, even though those words were not on the list. Participants falsely recognized an average of 1.83 of the synonyms (distracters) but only an average of 1.05 of the unrelated words. This result indicated a greater likelihood of semantic confusion.

Another way to show semantic encoding is to use sets of semantically related test words, rather than distracters. Participants learned a list of 60 words that included 15 animals, 15 professions, 15 vegetables, and 15 names of people (Bousfield, 1953). The words were presented in random order. Thus, words from various categories were intermixed thoroughly. After participants heard the words, they were asked to use free recall to reproduce the list in any order they wished. The investigator then analyzed the order of output of the recalled words. Did participants recall successive words from the same category more frequently than would be expected by chance? Indeed, successive recalls from the same category did occur much more often than would be expected by chance occurrence. Participants were remembering words by clustering them into categories. (You also can use categorical clustering as an intentional strategy to help you remember things like such as your shopping list. You will learn more about memory aids later in this chapter in Table 6.1 ■.)

Levels of processing, discussed in Chapter 5, also influences encoding in long-term memory. When learning lists of words, participants move more information into long-term memory when using a semantic encoding strategy than when using a nonsemantic strategy. Interestingly, this advantage is not seen in people with autism. This finding suggests that, in persons with autism, information may not be encoded semantically, or at least, not to the same extent as in people who do not have autism (Toichi & Kamio, 2002). When engaged in semantic processing, people with autism show less activation in Broca's area than do healthy participants. This finding indicates that Broca's area may be related to the semantic deficits autistic patients often exhibit (Harris et al., 2006).

Encoding of information in long-term memory is not exclusively semantic. There also is evidence for visual encoding. Participants in a study received 16 drawings of objects, including four items of clothing, four animals, four vehicles, and four items of furniture (Frost, 1972). The investigator manipulated not only the semantic category but also the visual category. The drawings differed in visual orientation. Four were angled to the left, four angled to the right, four horizontal, and four vertical. Items were presented in random order. Participants were asked to recall them freely. The order of participants' responses showed effects of both semantic and visual categories. These results suggested that participants were encoding visual as well as semantic information. In fact, research has shown people are able to store thousands of images (Brady et al., 2008).

Functional magnetic resonance imaging (fMRI) studies have found that the brain areas that are involved in encoding can be, but do not necessarily have to be, involved in retrieval. With respect to faces, the anterior medial prefrontal cortex and the right fusiform face area play an important role both in encoding and retrieval, whereas the left fusiform face area contributes mostly to encoding processes. Both encoding and retrieval of places activate the left parahippocampal place area (PPA); the left PPA is associated with encoding rather than retrieval. In addition, medial temporal and prefrontal regions are related to memory processes in general, no matter what kind of stimulus is used (Prince, Dennis, & Cabeza, 2009).

Acoustic information—in addition to semantic and visual information—can be encoded in long-term memory (Nelson & Rothbart, 1972). Thus, the way we store information that we retain for long periods is usually quite flexible. Those who seek to know the single correct way we encode information are seeking an answer to the wrong question. There is no one correct way. A more useful question involves asking, "In what *ways* do we encode information in long-term memory?" From a more psychological perspective, however, the most useful question to ask is, "*When* do we encode in *which* ways?" In other words, under what circumstances do we use one form of encoding, and under

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Table 6.1 Mnemonic Devices

Of the many mnemonic devices available, the ones described here rely either on organization of information into meaningful chunks, such as categorical clustering, acronyms, and acrostics, or on visual images, such as interactive images, a pegword system, and the method of loci.

Technique	Explanation/Description	Example
Categorical clustering (hierarchy technique)	Organize a list of items into a set of categories.	If you need to remember to buy specific food items, you would be better able to do so if you tried to memorize the items by categories: *fruits*—apples, grapes, grapefruit; *dairy products*—milk, yogurt, Swiss cheese; *breads*—bagels, rolls; *vegetables*—lettuce.
Interactive Images	Create interactive images that link the isolated words in a list.	To remember to buy socks, apples, and a pair of scissors, you might imagine using scissors to cut a sock that has an apple stuffed in it.
Pegword system	Associate each new word with a word on a previously memorized list and form an interactive image between the two words.	One such list is from a nursery rhyme: One is a bun. Two is a shoe. Three is a tree, and so on. To remember that you need to buy socks, apples, and a pair of scissors, you might imagine an apple between two buns, a sock stuffed inside a shoe, and a pair of scissors cutting a tree. When you need to remember the words, you first recall the numbered images and then recall the words as you visualize them in the interactive images.
Method of loci	Visualize walking around an area with distinctive landmarks that you know well, and then link the various landmarks to specific items to be remembered	Mentally walk past each of the distinctive landmarks, depositing each word to be memorized at one of the landmarks. Visualize an interactive image between the new word and the landmark. Suppose you have three landmarks on your route to school—a strange-looking house, a tree, and a baseball diamond. You might imagine a big sock on top of the house in place of the chimney, the pair of scissors cutting the tree, and apples replacing bases on the baseball diamond. When ready to remember the list, you would take your mental walk and pick up the words you had linked to each of the landmarks along the walk.
Acronym (first letter technique)	Devise a word or expression in which each of its letters stands for a certain other word or concept (e.g., USA, IQ, and laser)	Suppose that you want to remember the names of the mnemonic devices described in this chapter. The acronym "I AM PACK" might prompt you to remember Interactive images, Acronyms, Method of loci, Pegwords, Acrostics, Categories, and Keywords.
Acrostic	Form a sentence rather than a single word to help you remember the new words	Music students memorize the names of the notes found on lines of the treble clef (the higher notes; specifically *E, G, B, D*, and *F* above middle *C*) by learning that "*E*very *G*ood *B*oy *D*oes *F*ine."
Keyword system	Form an interactive image that links the sound and meaning of a foreign word with the sound and meaning of a familiar word.	To learn that the French word for butter is *beurre,* first, you would note that *beurre* sounds something like "bear." Next, you would associate the keyword "bear" with butter in an image or sentence. For instance, you might visualize a bear eating a stick of butter. Later, *bear* would provide a retrieval cue for *beurre.*

what circumstances do we use another? These questions are the focus of present and future research.

Transfer of Information from Short-Term Memory to Long-Term Memory

When we transfer information from short-term memory to long-term memory, we encounter two key problems: interference and decay. When competing information

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interferes with our storing information, we speak of **interference**. Imagine you have watched two crime movies with the same actor. You then try to remember the story line of one of the movies but mix it up with the second movie. You are experiencing interference. When we forget facts just because time passes, we speak of **decay**. These two concepts will be discussed in more detail later in this chapter.

Given the problems of decay and interference, how do we move information from short-term memory to long-term memory? How we move information depends on whether the information involves declarative or nondeclarative memory. Remember that declarative memory refers to facts and knowledge, whereas nondeclarative memory refers to procedural memories such as skills.

Some forms of nondeclarative memory are highly volatile and decay quickly. Examples are priming and habituation. Let's go back to our movie example and assume that one of the main protagonists in the movie was Tom Cruise. After the movie, you overhear a conversation in which the word "cruise" is mentioned. Automatically, Tom Cruise pops into your mind. If you hear the word "cruise" a few days later, however, Tom Cruise may not be so accessible in your mind, and instead, you may think of a cruise you recently took, or would like to take, in the Caribbean. Other nondeclarative forms are maintained more readily, particularly as a result of repeated practice (of procedures) or repeated conditioning (of responses).

Entrance into long-term declarative memory may occur through a variety of processes. One method of accomplishing this goal is by deliberately attending to information

Published in *The New Yorker*, April 25, 1983, © Ed Fisher/www.Cartoonbank.com

"The matters about which I'm questioned, Your Honor, are all things I should have included in my long-term memory but which I mistakenly inserted in my short-term memory."

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to comprehend it. Another is by making connections or associations between the new information and what we already know and understand. We make connections by integrating the new data into our existing schemas of stored information. This process of integrating new information into stored information is called **consolidation**. In humans, the process of consolidating declarative information into memory can continue for many years after the initial experience (Squire, 1986). When you learn about someone or something, for example, you often integrate new information into your knowledge a long time after you have acquired that knowledge. For example, you may have met a friend many years ago and started organizing that knowledge at that time. But you still acquire new information about that friend—sometimes surprising information—and continue to integrate this new information into your knowledge base.

Stress generally impairs the memory functioning. But, stress also can enhance the consolidation of memory through the release of hormones (Park et al., 2008; Roozendaal, 2002, 2003). The disruption of consolidation has been studied in amnesics. Studies have particularly examined people who have suffered brief forms of amnesia as a consequence of electroconvulsive therapy (ECT; Squire, 1986). For these amnesics, the source of the trauma is clear. Confounding variables can be minimized. A patient history before the trauma can be obtained, and follow-up testing and supervision after the trauma are more likely to be available. A range of studies suggests that during the process of consolidation, our memory is susceptible to disruption and distortion.

We may use various metamemory strategies to preserve or enhance the integrity of memories during consolidation (Metcalfe, 2000; Waters & Schneider, 2010). **Metamemory** strategies involve reflecting on our own memory processes to improve our memory. Such strategies are especially important when we are transferring new information to long-term memory by rehearsing it. Metamemory strategies are just one component of **metacognition**, our ability to think about and control our own processes of thought and ways of enhancing our thinking. Simply put, metacognition is thinking about how we think.

Rehearsal

One technique people use for keeping information active is **rehearsal**, the repeated recitation of an item. The effects of such rehearsal are termed *practice effects.* Rehearsal may be *overt,* in which case it is usually aloud and obvious to anyone watching. Or it may be *covert,* in which case it is silent and hidden.

Elaborative and Maintenance Rehearsal

To move information into long-term memory, an individual must engage in elaborative rehearsal. In *elaborative rehearsal,* the individual somehow elaborates on the items to be remembered. Such rehearsal makes the items either more meaningfully integrated into what the person already knows or more meaningfully connected to one another and therefore more memorable.

In contrast, consider maintenance rehearsal. In *maintenance rehearsal,* the individual simply repeats the items to be remembered. Such rehearsal temporarily maintains information in short-term memory without transferring the information to long-term memory. Without any kind of elaboration, the information cannot be organized and transferred (Tulving, 1962). This finding is important when you study for an exam. If you want to transfer facts to your long-term memory, you will need somehow to elaborate on the information and link it to what you already know. For example, if you meet a new acquaintance, you might encode not just the acquaintance's name but also other connections you have with the person, such as being members of a particular club or taking a particular course together. It will also be helpful to use mnemonic techniques like the ones discussed in the next section, but repeating words over and over again is not enough to achieve effective rehearsal.

The Spacing Effect

What is the best way to organize your time for rehearsing new information?

Our memory for information depends on how we acquire it. More than a century ago, Hermann Ebbinghaus (1885, cited in Schacter, 1989a; see also Chapter 1) noticed that the distribution of study (memory rehearsal) sessions over time affects the consolidation of information in long-term memory; more recently, research on people's recall of foreign language vocabulary, facts, and names of visual objects supports Ebbinghaus's finding (Cepeda et al., 2009). Our memories tend to be good when we use **distributed practice**, learning in which various sessions are spaced over time. Our memories for information are not as good when the information is acquired through **massed practice**, learning in which sessions are crammed together in a very short space of time (for a review, see Delaney, Verkoeijen, & Spirgel, 2010). The greater the distribution of learning trials over time, the more the participants remembered over long periods. To maximize the effect on long-term recall, the spacing should ideally be distributed over months, rather than days or weeks. This effect is termed the **spacing effect**. The research in this area is used by companies producing consumer products and advertising companies, among others. The goal of these companies is to anchor their products in your long-term memory so that you will remember them when you are in need of a particular product. The spacing in advertisements is varied to maximize the effect on your memory (Appleton-Knapp, Bjork, & Wickens, 2005). That means that a company will not place ads for the same product on several papers of a given magazine, but rather that they will place one ad every month in that magazine.

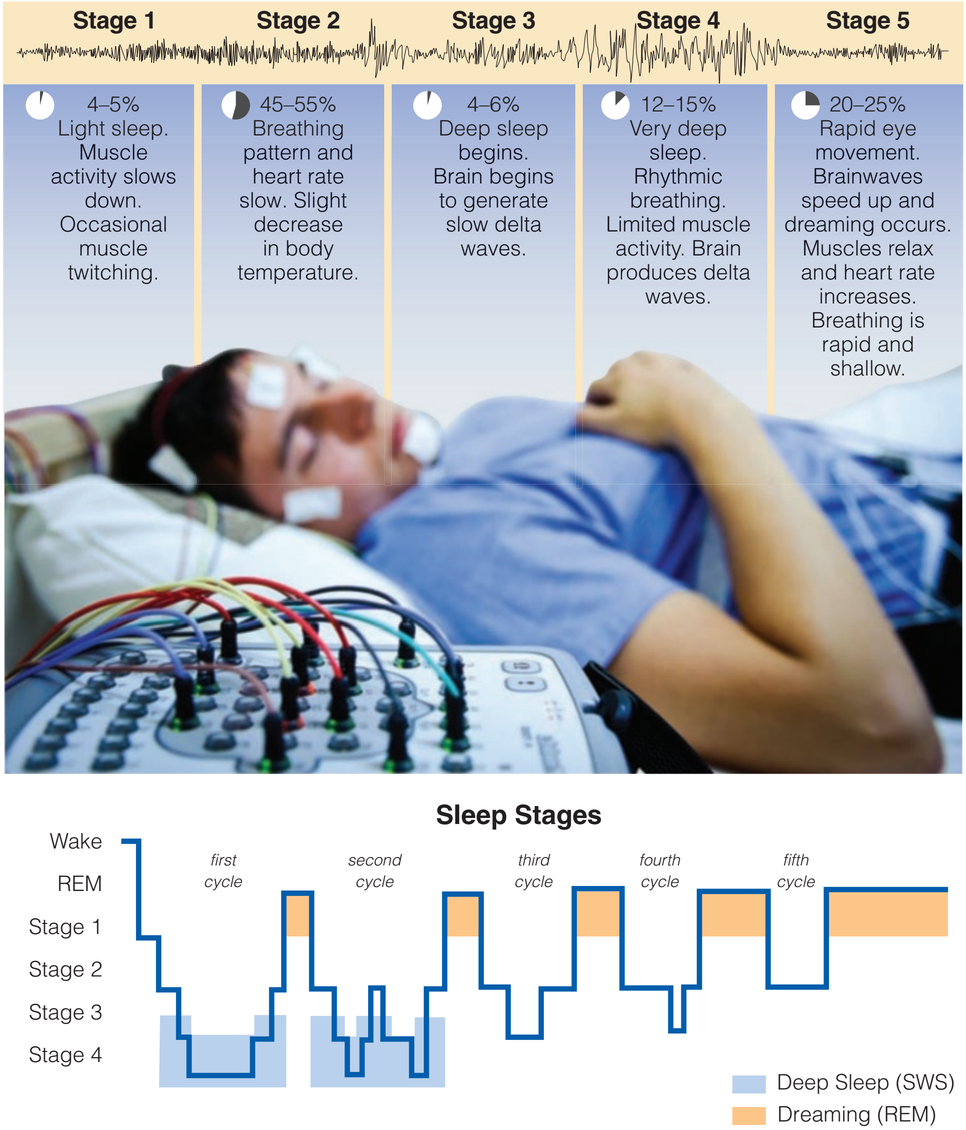
The spacing effect is linked to the process by which memories are consolidated in long-term memory (Glenberg, 1977, 1979; Leicht & Overton, 1987). That is, the spacing effect may occur because at each learning session, the context for encoding may vary. The individuals may use alternative strategies and cues for encoding. They thereby enrich and elaborate their schemas for the information. The principle of the spacing effect is important to remember in studying. You will recall information longer, on average, if you distribute your learning of subject matter over time and you vary the context for encoding. Do not try to cram it all into a short period. Imagine studying for an exam in several short sessions over a 2-week period. You will remember much of the material. If, however, you try to study all the material in just one night, you will remember very little and the memory for this material will decay relatively quickly.

Why would distributing learning trials over days make a difference? One possibility is that information is learned in variable contexts. These diverse contexts help strengthen and begin to consolidate it. Another possible answer comes from studies of the influences of sleep on memory.

Sleep and Memory Consolidation

Of particular importance to memory is the amount of rapid eye movement (REM) sleep a person receives. REM sleep is the sleep stage characterized by dreaming and increased brainwave activity (Karni et al., 1994; see Figure 6.1 ■).

Specifically, disruptions in REM sleep patterns the night after learning reduced the amount of improvement on a visual discrimination task that occurred relative to normal sleep. This lack of improvement was not observed for disrupted stage-three or


Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
4–5%
Light sleep. Muscle activity slows down. Occasional muscle twitching.
45–55%
Breathing pattern and heart rate slow. Slight decrease in body temperature.
4–6%
Deep sleep begins. Brain begins to generate slow delta waves.
12–15%
Very deep sleep. Rhythmic breathing. Limited muscle activity. Brain produces delta waves.
20–25%
Rapid eye movement. Brainwaves speed up and dreaming occurs. Muscles relax and heart rate increases. Breathing is rapid and shallow.
Sleep Stages
Wake
REM
Stage 1
Stage 2
Stage 3
Stage 4
first cycle
second cycle
third cycle
fourth cycle
fifth cycle
Deep Sleep (SWS)
Dreaming (REM)

wunkley/Alamy

■ **Figure 6.1** Five different sleep stages differ in their electroencephalogram patterns. Dreaming takes place during stage 5, the so-called REM sleep. REM sleep is particularly important for memory consolidation.

stage-four sleep patterns (Karni et al., 1994). Other research also shows better learning with increases in the proportion of REM-stage sleep after exposure to learning situations (Ellenbogen, Payne, & Stickgold, 2006; Smith, 1996). The positive influence of sleep on memory consolidation is seen across age-groups (Hornung et al., 2007).

People who suffer from insomnia, a disorder that deprives the sufferer of much-needed sleep, have trouble with memory consolidation (Backhaus et al., 2006). Thus, many studies have confirmed that REM sleeps aids us in the formation of memory (e.g., see Fischer et al., 2011). Research suggests that memory processes in the hippocampus are influenced by the production and integration of new cells into the neuronal network. REM sleep plays an important role in synaptic consolidation, whereby memories are strengthened that previously were organized in slow-wave (deep) sleep.

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Prolonged sleep deprivation seems to affect such cell development negatively (Diekelmann & Born, 2010; Meerlo et al., 2009). These findings highlight the importance of biological factors in the consolidation of memory. Thus, a good night's sleep, which includes plenty of REM-stage sleep, aids in memory consolidation. REM sleep not only can help us remember things but also may play a role in weakening memories of low value. Thus, REM sleep may help us not only to remember but also to forget certain things (Oudiette et al., 2013).

Neuroscience and Memory Consolidation

Is there something special occurring in the brain that could explain why REM sleep is so important for memory consolidation? Neuropsychological research on animal learning may offer a tentative answer to this question. Recall that the hippocampus has been found to be an important structure for memory. In studies of rat hippocampal cells, researchers have found that cells of the hippocampus that were activated during initial learning are reactivated during subsequent periods of sleep. It is as if they are replaying the initial learning episode to achieve consolidation into long-term storage (Scaggs & McNaughton, 1996; Wilson & McNaughton, 1994). This effect also has been observed in humans. After learning routes within a virtual town, participants slept. Increased hippocampal activity was seen during sleep after the person had learned the spatial information. In the people with the most hippocampal activation, there was also an improvement in performance when they needed to recall the routes (Peigneux et al., 2004). During this increased activity, the hippocampus also shows extremely low levels of the neurotransmitter acetylcholine. When patients were given acetylcholine during sleep, they showed impaired memory consolidation, but only for declarative information. Procedural memory consolidation was not affected by acetylcholine levels (Gais & Born, 2004).

The hippocampus acts as a rapid learning system (McClelland, McNaughton, & O'Reilly, 1995). It temporarily maintains new experiences until they can be appropriately assimilated into the more gradual neocortical representation system of the brain. Such a complementary system is necessary to allow memory to more accurately represent the structure of the environment. McClelland and his colleagues have used connectionist models of learning to show that integrating new experiences too rapidly leads to disruptions in long-term memory systems. Thus, the benefits of distributed practice seem to occur because we have a relatively rapid learning system in the hippocampus that becomes activated during sleep. Repeated exposure on subsequent days and repeated reactivation during subsequent periods of sleep help learning. These rapidly learned memories become integrated into our more permanent long-term memory system.

Furthermore, learning has a direct effect on the cells of your brain. The dentate gyrus in the hippocampus is an important brain region for memory formation, and new cells are generated there continuously—in fact, we're talking about thousands of new neurons each day (Cameron & McKay, 2001). However, many of these new cells die within a very short time. Experiments with animals have shown that if learning takes place before these cells are on the verge of death, the survival of these cells is enhanced (Sisti, Glass, & Shors, 2007).

Reconsolidation is a topic related to consolidation. The process of consolidation makes memories less likely to undergo either interference or decay. After a memory is called back into consciousness, however, it may return to a more unstable state. In this state, the memory that was consolidated may again fall victim to interference or decay. To prevent this loss, a process of reconsolidation takes place. Reconsolidation has the same effect that consolidation does, but it is completed on previously

practical applications of COGNITIVE PSYCHOLOGY

Memory Strategies

You can use these memory strategies to help you study for exams:

1. Study throughout the course rather than cram the night before an exam. This distributes the learning sessions, which allows for consolidation into more permanent memory systems.
2. Link new information to what you already know by rehearsing new information in meaningful ways. Organize new information to relate it to other coursework or areas of your life.
3. Use the various mnemonic devices shown in Table 6.1.
4. Quiz yourself or have others test you before the exam.
5. Be aware of the fluency illusion: When you reread a complex text it is easy to mistake your fluent reading of this text with your mastery of its complex content.
6. Build on your successful intelligence (see Chapter 13 for more information) to explore the topic you're studying from analytical, creative, and practical viewpoints.
7. Study the underlying principles of the field you are trying to master. If you find several example or studies, look at two of them and compare how they are similar and how they differ.

encoded information. Reconsolidation does not necessarily occur with each memory we recall but does seem to occur with relatively newly consolidated material (Walker et al., 2003).

Organization of Information

Stored memories are organized. One way to show how memories are organized is by measuring subjective organization in free recall. This means that researchers measure the different ways that individuals organize their memories. Researchers do this by giving participants a list of unrelated words to recall in any order (free recall). Participants have multiple trials during which to learn to recall a list of unrelated words in any order they choose. Remember that if sets of test words can be divided into categories (e.g., names of fruits or types of furniture), participants spontaneously will cluster their recall output by these categories. They do so even if the order of presentation is random (Bousfield, 1953). Similarly, participants will tend to show consistent patterns of word order in their recall, even if relations among words in the list are not apparent (Tulving, 1962). In other words, participants create their own consistent organization and then group their recall by the subjective units they create. Although most adults spontaneously tend to cluster items into categories, categorical clustering also may be used intentionally as an aid to memorization.

Mnemonic devices are specific techniques to help you organize and memorize information. These devices are especially helpful in memorizing lists of words because such devices add meaning to otherwise meaningless or arbitrary lists of items (Best, 2003). Even music can be used as a mnemonic device when a well-known or easy melody is used and connected with the material that needs to be learned. Music can serve as a retrieval cue. For example, if you want to learn vocabulary words in a foreign language for body parts, sing those words to yourself in a melody that you like and know well (e.g., see Moore et al., 2008).

As Table 6.1 shows, a variety of methods—categorical clustering, acronyms, acrostics, interactive imagery among items, pegwords, and the method of loci—can help you to memorize lists of words and vocabulary items. Although the techniques described in Table 6.1 are not the only available ones, they are among the most frequently used.

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What is the comparative effectiveness of the mnemonic strategies listed in Table 6.1? Henry Roediger (1980) conducted a study in which his participants used different strategies to memorize material. Roediger studied the initial recall of a series of items and recall following brief training in each of several memory strategies. For both free recall and serial recall, training in interactive imagery, the method of loci, and the pegword system was more effective than either verbal rehearsal or imagery for isolated items. Training effects were more pronounced in the serial recall condition. In the free recall condition, imagery of isolated items was more effective than verbal rehearsal, but for serial recall, verbal rehearsal was more effective than imagery for isolated items.

INVESTIGATING COGNITIVE PSYCHOLOGY

Test Your Short-Term Memory

Test your ability to retrieve information from your short-term memory. Try this memory-scanning test that is similar to the S. Sternberg experiment described in the chapter. Use 10 index cards and write one number on each card (1–10). Have a friend quickly show you five of the index cards (e.g., 6, 3, 8, 2, 7). Then, have your friend hold up one of the index cards and ask, “Is this one of the numbers?” Have your friend repeat this procedure five times. How often were you correct? Now, switch roles and test your friend’s short-term memory. How do people make decisions such as this one?

The relative effectiveness of the methods for encoding is influenced by the kind of task (free recall versus serial recall) required at the time of retrieval (Roediger, 1980). Thus, when choosing a method to encode information for subsequent recall, you should consider the purpose for recalling the information. You should choose strategies that not only allow for effectively encoding the information (moving it into long-term memory) but also offer appropriate cues for facilitating subsequent retrieval when needed. For example, using a strategy for retrieving an alphabetical list of prominent cognitive psychologists would probably be relatively ineffective before taking an exam in cognitive psychology. Using a strategy to link particular theorists with the key ideas of their theories is likely to be more effective.

Mnemonic devices and other techniques for aiding memory involve metamemory (our understanding and reflection upon our memory and how to improve it). Because most adults spontaneously use categorical clustering, its inclusion in this list of mnemonic devices is actually just a reminder to use this common memory strategy. In fact, each of us often uses various kinds of *reminders*—external memory aids—to enhance the likelihood that we will remember important information. For example, by now you surely have learned the benefits of various external memory aids. These include taking notes during lectures, writing shopping lists for items to purchase, setting timers and alarms, and even asking other people to help you remember things. In addition, we can design our environment to help us remember important information through the use of *forcing functions* (Norman, 1988). These are physical constraints that prevent us from acting without at least considering the key information to be remembered. For example, to ensure that you remember to take your notebook to class, you might lean the notebook against the door through which you must pass to go to class.

So-called forcing functions also are used in professional settings, such as hospitals, to change behavior. Patients in emergency rooms sometimes have to be physically

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restrained, but that restraint also significantly increases their risk of dying. The computer systems physicians use can force the physicians to reevaluate their decisions concerning the restraint orders by requiring them to renew the order and eventually blocking computer access if the renewal is not executed (Griffey et al., 2009). In effect, the physicians are forced to deal with the problem at hand. Mnemonic techniques also have been found to be helpful to assist school-age children with the addition and subtraction of fractions. The study used the Look-Ask-Pick mnemonic in which children where first instructed to "Look" at sign and denominators of the fractions, "Ask" whether the smallest denominator divides into the largest denominator an even number of times, and "Pick" a certain type of fraction to solve the mathematical task (Everett et al., 2014).

Most of the time, we try to improve our *retrospective memory*—our memory for the past. At times we also try to improve our *prospective memory*—memory for things we need to do or remember in the future. For example, we may need to remember to call someone, to buy cereal at the supermarket, or to finish a homework assignment due the next day. We use a number of strategies to improve prospective memory. Examples are keeping a to-do list, asking someone to remind us to do something, or tying a string around our finger to remind us that we need to do something. Research suggests that having to do something regularly on a certain day does not necessarily improve prospective memory for doing that thing. Being monetarily reinforced for doing the thing, however, does tend to improve prospective memory (Meacham, 1982; Meacham & Singer, 1977).

Prospective memory, like retrospective memory, is subject to decline as we age. Over the years, we retain more of our prospective memory than of our retrospective memory. This retention is likely the result of using the external cues and strategies that can be used to bolster prospective memory. In the laboratory, older adults show a decline in prospective memory; however, outside the laboratory, they show better performance than young adults. This difference may be due to greater reliance on strategies to aid in remembering as we age (Henry et al., 2004).

Neuroscience: How Are Memories Stored?

Where in the brain are memories stored, and what structures and areas of the brain are involved in memory processes, such as encoding and retrieval? Many early attempts at localization of memory were unfruitful. For example, after literally hundreds of experiments, renowned neuropsychologist Karl Lashley (1950) reluctantly stated that he could find no specific locations in the brain for specific memories. In the decades since Lashley's admission, psychologists have located many cerebral structures involved in memory. For example, they know of the importance of the hippocampus and other nearby structures. The physiological structure, however, may not be such that we will find Lashley's elusive localizations of specific ideas, thoughts, or events. Even Penfield's findings regarding links between electrical stimulation and episodic memory of events have been subject to question.

Some studies show encouraging, although preliminary, findings regarding the structures that seem to be involved in various aspects of memory. First, specific sensory properties of a given experience appear to be organized across various areas of the cerebral cortex (Squire, 1986). For example, the visual, spatial, and olfactory (odor) features of an experience may be stored discretely in each of the areas of the cortex responsible for processing each type of sensation. Thus, the cerebral cortex appears to play an important role in memory in terms of the long-term storage of information (Zola & Squire, 2000; Zola-Morgan & Squire, 1990).

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In addition, the hippocampus and some related nearby cerebral structures appear to be important for explicit memory of experiences and other declarative information. The hippocampus also seems to play a key role in the encoding of declarative information (Manns & Eichenbaum, 2006; Thompson, 2000). Its main function appears to be in the integration and consolidation of separate sensory information as well as spatial orientation and memory (Ekstrom et al., 2003; Moscovitch, 2003; Solstad et al., 2008). Most important, it is involved in the transfer of newly synthesized information into long-term structures supporting declarative knowledge. Perhaps such transfer provides a means of cross-referencing information stored in different parts of the brain (Reber, Knowlton, & Squire, 1996). Additionally, the hippocampus seems to play a crucial role in complex learning (Gupta et al., 2009; McCormick & Thompson, 1984). Finally, the hippocampus also has a significant role in the recollection of information (Gilboa et al., 2006).

In evolutionary terms, the aforementioned cerebral structures (chiefly the cortex and the hippocampus) are relatively recent acquisitions. Declarative memory also may be considered a relatively recent phenomenon. At the same time, other memory structures may be responsible for nondeclarative forms of memory. For example, the basal ganglia seem to be the primary structures controlling procedural knowledge (Shohamy et al., 2009). But they are not involved in controlling the priming effect (Heindel, Butters, & Salmon, 1988), which may be influenced by various other kinds of memory (Schacter, 1989b). Furthermore, the cerebellum also seems to play a key role in memory for classically conditioned responses and contributes to many cognitive tasks in general (Thompson & Steinmetz, 2009). Thus, various forms of nondeclarative memory seem to rely on differing cerebral structures.

The amygdala often is associated with emotional events, so a natural question to ask is whether memory tasks involve the amygdala in memory for emotionally charged events. In one study, participants saw two video presentations presented on separate days (Cahill et al., 1996). Each presentation involved 12 clippings, half of which had been judged as involving relatively emotional content and the other half as involving relatively unemotional content. As participants watched the video clippings, brain activity was assessed by means of positron emission tomography (PET; see Chapter 2). After a gap of 3 weeks, the participants returned to the lab and were asked to recall the clips. For the relatively emotional clips, some amount of activation in the amygdala was associated with recall; for the relatively unemotional clips, there was no association. This pattern of results suggests that when memories are emotionally charged, the level of amygdala activation is associated with recall. In other words, the more emotionally charged the emotional memory, the greater the probability the memory will later be retrieved. There also may be a gender difference with regard to recall of emotional memories. Some evidence suggests that women recall emotionally charged pictures better than do men (Canli et al., 2002). The amygdala also appears to play an important role in memory consolidation, especially in cases in which emotional experience is involved (Cahill & McGaugh, 1996; Roozendaal, Barsegyan, & Lee, 2008).

In addition to these preliminary insights regarding the macrolevel structures of memory, we are beginning to understand the microlevel structure of memory. For example, we know that repeated stimulation of particular neural pathways tends to strengthen the likelihood of firing. This is called *long-term potentiation* (in which potentiation refers to an increase in activity). In particular, at a particular synapse, there appear to be physiological changes in the dendrites of the receiving neuron. These changes make the neuron more likely to reach the threshold for firing again. This finding is very important because it indicates that neurons in the hippocampus may be able to change their interactions (i.e., that they are *plastic*).

The idea that new experiences and learning can lead to changes in synapses in the brain has been around for a long time (Hebb, 1948). The repeated activity of a synapse can lead to structural changes that eventually can lead to *long-term potentiation* (i.e., an increase in the synaptic response and thus an increase in the firing rate). Thus, new experiences can lead to changes in many thousands of synapses and therefore be represented in the brain by a particular activation pattern across a group of neurons. New research has now found that learning and thus the formation of new information in our memory can involve the formation of new synapses as well as the loss of old synapses (Caroni, Chowdhury, & Lahr, 2014).

Furthermore, brain oscillations (repetitive neural activity) may play a role in the formation of memories. It is not clear, however, how those neural oscillations are related to memory formation because oscillations of all frequency bands, and decreasing as well increasing amplitudes, have been found to be involved. So the answer will likely be a complex one, with some researchers hypothesizing that the depth of information processing (see the levels of processing approach described earlier in this chapter) may play a key role (Hanslmayr & Staudigl, 2014).

We also know that some neurotransmitters disrupt memory storage. Others enhance memory storage. Both serotonin and acetylcholine seem to enhance neural transmission associated with memory. Norepinephrine also may do so. High concentrations of acetylcholine have been found in the hippocampus of normal people (Squire, 1987), but low concentrations are found in people with Alzheimer's disease. In fact, Alzheimer's patients show severe loss of the brain tissue that secretes acetylcholine.

Serotonin also plays a role in another form of memory dysfunction, *Korsakoff syndrome*. Severe or prolonged abuse of alcohol can lead to this devastating form of anterograde amnesia. Alcohol consumption has been shown to disrupt the activity of serotonin. It thereby impairs the formation of memories (Weingartner et al., 1983). This syndrome is often accompanied by at least some retrograde amnesia (Clark et al., 2007). Korsakoff's syndrome has been linked to damage in the diencephalon (the region made up of the thalamus and the hypothalamus) of the brain (Postma, Wester, & Kessels, 2008). It also has been linked to dysfunction or damage in other areas, such as in the frontal and the temporal lobes of the cortex (Jacobson, Acker, & Lishman, 1990; Kopelman et al., 2009; Reed et al., 2003).

Other physiological factors also affect memory function. Some of the naturally occurring hormones stimulate increased availability of glucose in the brain, which enhances memory function. These hormones often are associated with highly arousing events. Examples of such events are traumas, achievements, first-time experiences (e.g., first passionate kiss), crises, or other peak moments (e.g., reaching a major decision). Hormones may play a role in remembering these events.

Some of the most fascinating research in cognitive psychology focuses on the strategies used in regard to memory. Memory strategies and memory processes are the subject of the following chapter.

CONCEPT CHECK

1. How does encoding differ in the short-term storage and the long-term storage?
2. What is rehearsal?
3. Name and explain three mnemonic devices.

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Retrieval

Once we have encoded and stored information in short-term memory, how do we retrieve it? If we have problems retrieving information, was the information even stored in the first place?

Retrieval from Short-Term Memory

In one study on memory scanning, Saul Sternberg (1966) presented participants with a short list including from one to six digits. They were expected to hold the list in short-term memory. After a brief pause, a test digit was flashed on a screen. Participants had to say whether this digit appeared in the set that they had been asked to memorize. Thus, if the list included the digits 4, 1, 9, 3, and the digit 9 flashed on the screen, the correct response would be "yes." If, instead, the test digit was 7, the correct response would be "no." The digits that were presented are termed the *positive set.* Those that were not presented are termed the *negative set.* ■ Go to Lab 22, the Sternberg Search, in CogLab to explore a similar experiment.

Sternberg conducted this experiment to answer several questions: Are items retrieved all at once (parallel processing) or sequentially (serial processing)? If retrieved serially, the question then arises: Are all items retrieved, regardless of the task (exhaustive retrieval), or does retrieval stop as soon as an item seems to accomplish the task (self-terminating retrieval)? In the next sections, we examine parallel and serial processing as well as exhaustive and self-terminating retrieval and make predictions about how Sternberg's results should look depending on which processes take place. Then we'll return to his experiment to see the actual results of his study.

Let's think about these different options for retrieving memories and see what the research results say.

Parallel or Serial Processing?

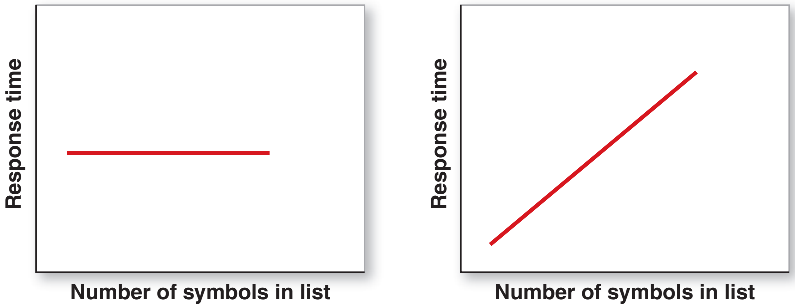
Parallel processing refers to the simultaneous handling of multiple operations. As applied to short-term memory, the items stored in short-term memory would be retrieved all at once, not one at a time. The prediction in Figure 6.2(a) ■ shows what would happen if parallel processing were the case in the Sternberg memory scanning task: Response times should be the same, regardless of how many numbers were presented (i.e., how many number were in the positive set). This is because all comparisons would be done at once.

Serial processing refers to operations being done one after another. In other words, on the digit-recall task, the digits would be retrieved in succession, rather than all at once (as in the parallel model). According to the serial model, the more numbers that were presented in the positive set, the longer it should take to retrieve them [as shown in Figure 6.2(b) ■].

Exhaustive or Self-Terminating Processing?

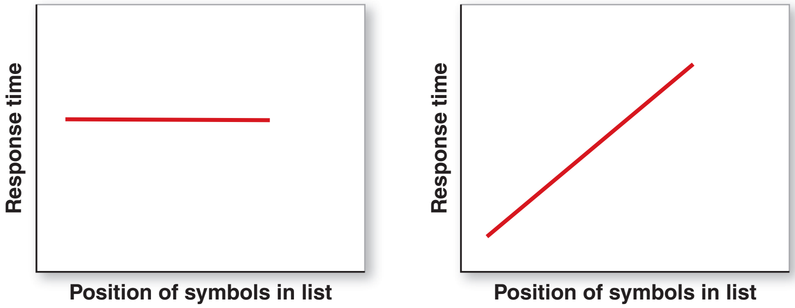
If information processing were serial, there would be two ways in which to gain access to the stimuli: exhaustive or self-terminating processing. *Exhaustive serial processing* implies that the participant always checks the test digit against *all* digits in the positive set, even if a match were found partway through the list.

Positive responses all would take the same amount of time, regardless of whether the test digit was located in the beginning or end of the list of numbers presented. In other



(a) Parallel processing

(b) Serial processing



(c) Exhaustive serial processing

(d) Self-terminating serial processing

■ **Figure 6.2** This figure shows the four possible predictions for retrieval from short-term memory of Saul Sternberg's experiment. Participants have to respond to the question whether a given number was presented before in the positive set. The panels show **(a) parallel processing**—response time is the same no matter how many numbers were originally presented in the positive set; **(b) serial processing**—the more numbers were in the positive set, the longer is the response time; **(c) exhaustive serial processing**—response time is always the same, no matter where the test digit was located in the positive set; and **(d) self-terminating serial processing**—response time increases as the test digit is located later in the positive set.

Source: Based on S. Sternberg (1966), "High Speed in S. Sternberg's Short-Term Memory-Scanning Task," *Science,* Vol. 153, pp. 652–654. Copyright © 1966 American Association for the Advancement of Science.

words, in an exhaustive search, you would take the same amount of time to find any digit. Exhaustive processing would predict the pattern of data shown in Figure 6.2(c) ■.

Self-terminating serial processing implies that the participant would check the test digit against only those digits needed to make a response. Once the test digit has been located, the process is terminated. Consider Figure 6.2(d) ■. It shows that response time now would increase linearly as a function of where a particular test digit was located in the positive set. The later the serial position, the longer is the response time.

The Winner—a Serial Exhaustive Model—with Some Qualifications

The actual pattern of data was crystal clear. The data looked like those in Figures 6.2(b) and 6.2(c). Response times increased linearly with set size, but they were the same, regardless of serial position. Later, this pattern of data was replicated (Sternberg, 1969). Moreover, the mean response times for positive and negative responses were essentially the same. This fact further supported the serial exhaustive model. Comparisons took roughly 38 milliseconds (0.038 seconds) apiece (Sternberg, 1966, 1969).

Although many investigators considered the question of parallel versus serial processing to have been answered decisively, in fact, a parallel model could account for the data (Corcoran, 1971). Imagine a horse race that involves parallel processing. The race is not over until the last horse passes the finish line. Now, suppose we add more horses to the race. The length of the race, from the start until the last of the horses crosses the finishing line, is likely to increase. For example, if horses are selected randomly, the slowest horse in an eight-horse race is likely to be slower than the slowest horse in a four-horse race. That is, with more horses, a wider range of speeds is more likely. So the entire race will take longer because the race is not complete until the slowest horse crosses the finish line.

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Similarly, when applying a parallel model to a retrieval task involving more items, a wider range of retrieval speeds for the various items is also more likely. The entire retrieval process is not complete until the last item has been retrieved. Mathematically, it is impossible to distinguish parallel from serial models unequivocally (Townsend, 1971). Some parallel model always exists that will mimic any serial model in its predictions and vice versa. The two models may not be equally plausible, but they still exist. Moreover, it appears that which processes individuals use depends in part on the stimuli that are processed (e.g., Naus, 1974; Naus, Glucksberg, & Ornstein, 1972).

Some cognitive psychologists have suggested that we should seek not only to understand the *how* of memory processes but also the *why* of memory processes (e.g., Bruce, 1991). That is, what functions does memory serve for individuals and for humans as a species? To understand the functions of memory, we must study memory for relatively complex information. We also need to understand the relationships between the information presented and other information available to the individual, both within the informational context and as a result of prior experience.

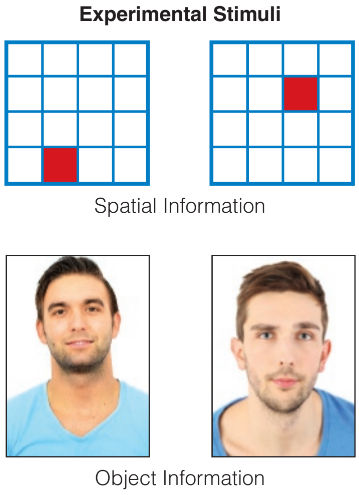
Retrieval from Long-Term Memory

It is difficult to separate storage from retrieval phenomena. Participants in one study were tested on their memory for lists of categorized words (Tulving & Pearlstone, 1966). Participants would hear words within a category together in the list and would be given the name of the category before the items within it were presented. For example, the participants might hear the category "article of clothing" followed by the words "shirt, socks, pants, belt." Participants then were tested for their recall.

The recall test was done in one of two ways. In the free recall condition, participants merely recalled as many words as they could in any order they chose. In a cued recall condition, however, participants were tested category by category. They were given each category label as a cue. They then were asked to recall as many words as they could from that category. The critical result was that cued recall was far better, on average, than free recall. Had the researchers tested only free recall, they might have concluded that participants had not stored quite so many words. The comparison to the cued recall condition, however, demonstrated that apparent memory failures were largely a result of retrieval, rather than storage failures.

Categorization dramatically can affect retrieval. In another study, participants learned lists of categorized words (Bower et al., 1969). Either the words were presented in random order or they were presented in the form of a hierarchical tree that showed the organization of the words. For example, the category "minerals" might be at the top, followed by the categories of "metals and stones," and so on. Participants given hierarchical presentation recalled 65% of the words. In contrast, recall was just 19% by participants given the words in random order.

An interesting study by Khader et al. (2005) demonstrated that material that is processed in certain cortical areas during perception also activates those same areas again during long-term memory recall. Participants learned abstract words that were connected either with one or two faces or with one or two spatial positions (see Figure 6.3 ■). A few days later in a cued recall task, they were presented with two



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■ **Figure 6.3** In the experiment of Khader et al. (2005), participants were presented with abstract words like "concept," which were paired with either one or two spatial positions or faces.

Source: Based on Khader, P., Burke, M., Bien, S., Ranganath, C., & Roesler, F. (2005). Content-specific activation during associative long-term memory retrieval, *Neuroimage, 27*(4), 805–816.

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words and were asked to decide whether those two words were connected by a common face or position, with their performance recorded by fMRI. Recall of spatial positions activated areas, such as the parietal and precentral cortex, and faces activated areas, such as the left prefrontal temporal cortex and the posterior cingulated cortex. Blood oxygen levels increased with the number of associations to be recalled.

Another problem that arises when studying memory is figuring out why we sometimes have trouble retrieving information. Cognitive psychologists often have difficulty finding a way to distinguish between availability and accessibility of items. **Availability** is the presence of information stored in long-term memory. **Accessibility** is the degree to which we can gain access to the available information. Memory performance depends on the accessibility of the information to be remembered. Ideally, memory researchers would like to assess the availability of information in memory. Unfortunately, they must settle for assessing the accessibility of such information.

✓ CONCEPT CHECK

1. How do we retrieve data from short-term memory?
2. Why do we need to make a difference between the *availability* and the *accessibility* of information?

Processes of Forgetting and Memory Distortion

Why do we so easily and so quickly forget phone numbers we have just looked up or the names of people whom we have just met? Several theories have been proposed as to why we forget information stored in working memory. The two most well-known theories are interference theory and decay theory. Interference occurs when competing information causes us to forget something; decay occurs when the passage of time causes us to forget.

Interference Theory

Interference theory refers to forgetting that occurs because recall of certain words interferes with recall of other words. Evidence for interference goes back many decades (Brown, 1958; Peterson & Peterson, 1959). In one study, participants were asked to recall *trigrams* (strings of three letters) at intervals of 3, 6, 9, 12, 15, or 18 seconds after the presentation of the last letter (Peterson & Peterson, 1959). The investigators used only consonants so that the trigrams would not be easily pronounceable—for example, “K B F.” Figure 6.4 ■ shows percentages of correct recalls after the various intervals of time.

Why does recall decline so rapidly? Because after the oral presentation of each trigram, participants counted backward by threes from a three-digit number spoken immediately after the trigram. The purpose of having the participants count backward was to prevent them from rehearsing during the *retention interval.* This is the time between the presentation of the last letter and the start of the recall phase of the experimental trial.

Clearly, the trigram is almost completely forgotten after just 18 seconds if participants are not allowed to rehearse it. Moreover, such forgetting also occurs when words rather than letters are used as the stimuli to be recalled (Murdock, 1961). So, counting backward interfered with recall from short-term memory, supporting the interference account of forgetting in short-term memory. At that time, it seemed surprising that

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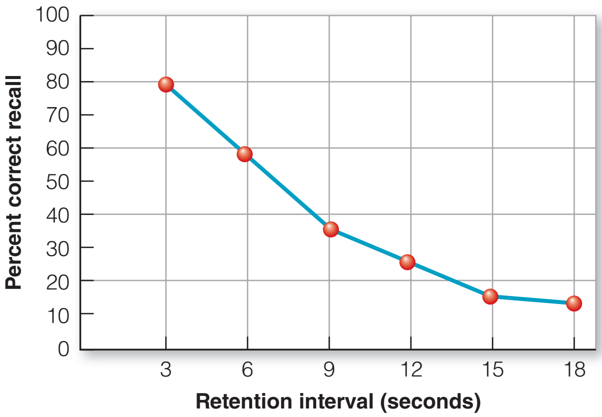

■ **Figure 6.4** The percentage of recall of three consonants (a trigram) drops off quickly if participants are not allowed to rehearse the trigrams.

Source: Based on G. Keppel and B. J. Underwood (1962), "Proactive Inhibition in Short-Term Retention of Single Items," *Journal of Verbal Learning and Verbal Behavior,* 1, pp. 153–161.

counting backward with numbers would interfere with the recall of letters. The previous view had been that verbal information would interfere only with verbal (words) memory. Similarly, it was thought that quantitative (numerical) information would interfere only with quantitative memory.

At least two kinds of interference figure prominently in psychological theory and research: retroactive interference and proactive interference. **Retroactive interference** (or retroactive inhibition) occurs when newly acquired knowledge impedes the recall of older material. This kind of interference is caused by activity occurring *after* we learn something but *before* we are asked to recall that thing. The interference in the Brown-Peterson task appears to be retroactive because counting backward by threes occurs after learning the trigram. It interferes with our ability to remember information we learned previously. ■ To explore the Brown-Peterson experiment, see Lab 20, Brown-Peterson in CogLab.

Proactive interference (or proactive inhibition) occurs when material that was learned in the past impedes the learning of new material. In this case, the interfering material occurs *before,* rather than *after,* learning of the to-be-remembered material. If you have studied more than one foreign language, you may have experienced this effect quite intensely. The author studied French at school, and then started learning Spanish when she entered college. Unfortunately, French words found their way into her Spanish essays unnoticed, and it took her a while to eliminate those French words from her writing in Spanish (proactive interference). Later, she studied Italian, and because she had not practiced Spanish in a few years, when she formulated Spanish sentences in a conversation without much time to think, there was a good chance a mixture of Italian and Spanish would emerge (retroactive interference).

Proactive as well as retroactive interference may play a role in short-term memory (Keppel & Underwood, 1962; Makovski & Jiang, 2008). Thus, retroactive interference appears to be an important (Reitman, 1971; Shiffrin, 1973; Waugh & Norman, 1965), but not the only, factor impeding memory performance.

The amount of proactive interference generally climbs with increases in the length of time between when the information is presented (and encoded) and when the information is retrieved (Underwood, 1957). Also, as you might expect, proactive interference increases as the amount of prior—and potentially interfering—learning increases (Greenberg & Underwood, 1950). Proactive interference generally has stronger effects in older adults than in younger people (Ebert & Anderson, 2009). Both proactive and retroactive interference can be reduced by sleep, which is another indicator of the importance of sleep in memory consolidation (Abel & Bäuml, 2014).

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Proactive interference seems to be associated with activation in the frontal cortex. In particular, it activates Brodmann area 45 in the left hemisphere (Postle, Brush, & Nick, 2004). In alcoholic patients, proactive interference is seen to a lesser degree than in nonalcoholic patients. This finding suggests that the alcoholic patients have difficulty integrating past information with new information. Thus, alcoholic patients may have difficulty binding together unrelated items in a list (De Rosa & Sullivan, 2003). Taken together, these findings suggest that Brodmann area 45 is likely involved in the binding of items into meaningful groups. When more information is gathered, an attempt to relate them to one another can occupy much of the available resources, leaving limited processing ability for new items.

All information does not equally contribute to proactive interference. For instance, if you are learning a list of numbers, your performance in learning the list will decline gradually as the list continues. If, however, the list switches to words, your performance will rebound. This enhancement in performance is known as *release from proactive interference* (Bunting, 2006). The effects of proactive interference appear to dominate under conditions in which recall is delayed. Proactive and retroactive interference, however, now are viewed as complementary phenomena.

Some early psychologists recognized the need to study memory retrieval for connected texts and not just for unconnected strings of digits, words, or nonsense syllables. In one study, participants learned a text and then recalled it (Bartlett, 1932). British participants learned a North American Indian legend called "The War of the Ghosts," which to them was a strange and difficult-to-understand text. Read the legend in *Investigating Cognitive Psychology: Bartlett's Legend* and test yourself to see how much of the legend you can recall.

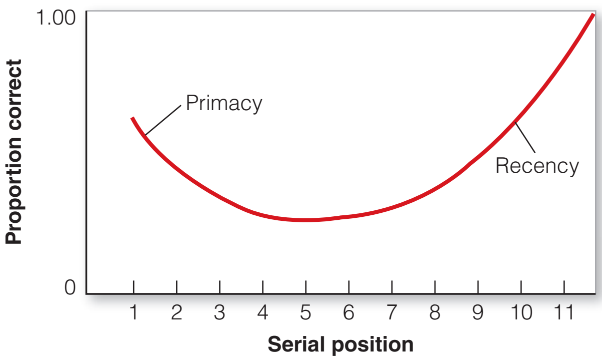
Participants distorted their recall to render the story more comprehensible to themselves. In other words, their prior knowledge and expectations had a substantial effect on their recall. Apparently, people bring existing schemas to memory tasks, which affect the way in which they recall what they learn. **Schemas** are mental frameworks that represent knowledge in a meaningful way. The later work using the Brown-Peterson paradigm confirms the notion that prior knowledge has an enormous effect on memory, sometimes leading to interference or distortion.

Another method often used for determining the causes of forgetting involves the serial-position curve. The **serial-position curve** represents the probability of recall of a given word, given its serial position (order of presentation) in a list. Suppose that you are presented with a list of words and are asked to recall them. You even might try it on yourself with the boxed feature *Investigating Cognitive Psychology: The Serial-Position Curve*, or ■ try Lab 31, Serial Position, in CogLab.

If you are like most people, you will find that your recall of words is best for items at and near the end of a list. Your recall will be second best for items near the beginning of the list and poorest for items in the middle of the list. A typical serial-position curve is shown in Figure 6.5 ■.

The **recency effect** refers to superior recall of words at and near the end of a list. The **primacy effect** refers to superior recall of words at and near the beginning of a list. As Figure 6.5 shows, both the recency effect and the primacy effect seem to influence recall. The serial-position curve makes sense in terms of interference theory. Words at the end of the list are subject to proactive but not to retroactive interference. Words at the beginning of the list are subject to retroactive but not to proactive

■ **Figure 6.5** When asked to recall a list of words, we show superior recall of words close to the end of a list (the recency effect), pretty good recall of words close to the beginning of the list (primacy effect), and relatively poor recall of words in the middle of the list.



INVESTIGATING COGNITIVE PSYCHOLOGY

Can You Recall Bartlett's Legend?

Read the following legend and then turn the page so you cannot see the story. Now, try to recall the legend in its entirety by writing down what you remember.

(A) Original Indian Myth

The War of the Ghosts

One night two young men from Egulac went down to the river to hunt seals, and while they were there it became foggy and calm. Then they heard war-cries, and they thought: "Maybe this is a war-party." They escaped to the shore, and hid behind a log.

Now canoes came up, and they heard the noise of paddles, and saw one canoe coming up to them. There were five men in the canoe, and they said:

"What do you think? We wish to take you along. We are going up the river to make war on the people."

One of the young men said, "I have no arrows."

"Arrows are in the canoe," they said.

"I will not go along. I might be killed. My relatives do not know where I have gone. But you," he said, turning to the other, "may go with them."

So one of the young men went, but the other returned home.

And the warriors went on up the river to a town on the other side of Kalama. The people came down to the water, and they began to fight, and many were killed. But presently the young man heard one of the warriors say: "Quick, let us go home; that Indian has been hit." Now he thought: "Oh, they are ghosts." He did not feel sick, but they said he had been shot.

So the canoes went back to Egulac, and the young man went ashore to his house, and made a fire. And he told everybody and said: "Behold I accompanied the ghosts, and we went to fight. Many of our fellows were killed, and many of those who attacked us were killed. They said I was hit, and I did not feel sick."

He told it all, and then he became quiet.

When the sun rose he fell down. Something black came out of his mouth. His face became contorted. The people jumped up and cried.

He was dead.

(B) Typical Recall by a Student in England

The War of the Ghosts

Two men from Edulac went fishing. While thus occupied by the river they heard a noise in the distance.

"It sounds like a cry," said one, and presently there appeared some in canoes who invited them to join the party of their adventure. One of the young men refused to go, on the ground of family ties, but the other offered to go.

"But there are no arrows," he said.

"The arrows are in the boat," was the reply.

He thereupon took his place, while his friend returned home. The party paddled up the river to Kaloma, and began to land on the banks of the river. The enemy came rushing upon them, and some sharp fighting ensued. Presently someone was injured, and the cry was raised that the enemy were ghosts.

The party returned down the stream, and the young man arrived home feeling none the worse for his experience. The next morning at dawn he endeavored to recount his adventures. While he was talking something black issued from his mouth. Suddenly he uttered a cry and fell down. His friends gathered round him.

But he was dead.

Source: "The War of the Ghosts," from *Remembering: A Study in Experimental and Social Psychology* by F. C. Bartlett. Copyright © 1932 by Cambridge University Press.

interference. And words in the middle of the list are subject to both types of interference. Therefore, recall would be expected to be poorest in the middle of the list. Indeed, it is poorest.

Primacy and recency effects can also be encountered in everyday life. Have you noticed that when you meet someone and then get to know him or her better, it can sometimes be very hard to get over your first impressions? This difficulty may be a result

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INVESTIGATING COGNITIVE PSYCHOLOGY

The Serial-Position Curve

Get at least two or three friends or family members to help you with this experiment. Tell them that you are going to read a list of words and as soon as you finish, they are to write down as many words as they can remember in any order they wish. (Make sure everyone has paper and a pencil.) Read the following words to them about 1 second apart: *book, peace, window, run, box, harmony, hat, voice, tree, begin, anchor, hollow, floor, area, tomato, concept, arm, rule, lion, hope*. After giving them enough time to write down all of the words they can remember, total their number of recollections in the following groups of four:

1. *book, peace, window, run*
2. *box, harmony, hat, voice*
3. *tree, begin, anchor, hollow*
4. *floor, area, tomato, concept*
5. *arm, rule, lion, hope*

Most likely, your friends and family will remember more words from groups 1 and 5 than from groups 2, 3, and 4, with group 3 the least recalled group. This exercise demonstrates the serial-position curve. Save the results of this experiment for a demonstration in Chapter 7.

INVESTIGATING COGNITIVE PSYCHOLOGY

Primacy and Recency Effects

Say the following list of words once to yourself, and then, immediately try to recall all the words, in any order, without looking back at them: *table, cloud, book, tree, shirt, cat, light, bench, chalk, flower, watch, bat, rug, soap, pillow.* If you are like most people, you will find that your recall of words is best for items at and near the end of the list. Your recall will be second best for items near the beginning of the list and poorest for items in the middle of the list. A typical serial-position curve is shown in Figure 6.5.

of a primacy effect, which leads to your remembering your first impression particularly well. And if you are applying for a job and are doing interviews, being one of the first or last candidates interviewed may benefit you in the hope that your interviewers will remember you better and more clearly than the candidates whose turns were in the middle.

Decay Theory

In addition to interference theory, another theory explains how we forget information—decay theory. **Decay theory** asserts that information is forgotten because of the gradual disappearance, rather than displacement, of the memory trace. Thus, decay theory views

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the original piece of information as gradually disappearing unless something is done to keep it intact. This view contrasts with interference theory, in which one or more pieces of information block recall of another.

Decay theory turns out to be exceedingly difficult to test because under normal circumstances, preventing participants from rehearsing is difficult. Through rehearsal, participants maintain the to-be-remembered information in memory. Usually participants know that you are testing their memory. They may try to rehearse the information or they may inadvertently rehearse it to perform well during testing. However, if you do prevent them from rehearsing, the possibility of interference arises. The task you use to prevent rehearsal may interfere retroactively with the original memory.

For example, try not to think of white elephants as you read the next two pages. When instructed not to think about them, you actually find it quite difficult not to. The difficulty persists even if you try to follow the instructions. Unfortunately, as a test of decay theory, this experiment is itself a white elephant because preventing people from rehearsing is so difficult.

Despite these difficulties, it is possible to test decay theory. A research paradigm called the "recent-probes task" has been developed that does not encourage participants to rehearse the items presented (Berman, Jonides, & Lewis, 2009; Monsell, 1978). It is based on the item-recognition task of S. Sternberg (1966) presented earlier in this chapter. Here is the recent-probes task:

- Participants are shown four target words.
- Next, participants are presented with a probe word.
- Participants decide whether or not the probe word is identical to one of the four target words.

If the probe word is not the same as the target words but is identical to a target word from a recent prior set of target words ("recent negative"), then it will take participants longer to decide that probe word and target words do not match than if the probe word is completely new.

The response delay, which is usually between 50–100 milliseconds, is a result of the high familiarity of the probe word. That is, the recent-probes task elicits clear interference effects. Of interest to researchers is the *intertrial interval* (the time between the presentation of one set of target words and subsequent probe), which can easily be varied. After each set of stimuli, participants have no incentive to rehearse the target words, so the longer the intertrial interval, the more time passes and the more are the target words subject to decay in memory. Thus, if memory decay results from time passing by, then recent negative probes in trials with a longer intertrial interval should not be as interfering of memory performance as recent negative probes in trials with a shorter intertrial time. So even if both decay and interference contribute to forgetting, it can be argued that interference has the strongest effect (Berman et al., 2009). And this is exactly what researchers found:

- Decay only had a relatively small effect on forgetting in short-term memory.
- Interference accounted for most of the forgetting.
- So even if both decay and interference contribute to forgetting, it can be argued that interference has the stronger effect (Berman et al., 2009).

To conclude, evidence exists for both interference and decay, at least in short-term memory. There is some evidence for decay, but the evidence for interference is much stronger. For now, we can assume that interference accounts for most of the forgetting in short-term memory. However, the extent to which the interference is retroactive, proactive, or both is unclear. In addition, interference also affects material in long-term memory, leading to memory distortion.

CONCEPT CHECK

1. Name and define two types of interference.
2. What is the recency effect?
3. What is the difference between interference and decay?

The Constructive Nature of Memory

An important lesson about memory is that memory retrieval is not just **reconstructive**, involving the use of various strategies (e.g., searching for cues, drawing inferences) to retrieve the original memory traces of our experiences and then rebuild the original experiences as a basis for retrieval (for an artificial-intelligence model of reconstructive memory, see Kolodner, 1983). Rather, in real-life situations, memory is also **constructive**, in that prior experience affects how we recall things and what we actually recall from memory (Davis & Loftus, 2007; Grant & Ceci, 2000; Sutton, 2003). Think back to the Bransford and Johnson (1972) study, cited at the opening of this chapter. In this study, participants could remember a passage about washing clothes quite well but only if they realized that it was about washing clothes.

In a further demonstration of the constructive nature of memory, participants read an ambiguous passage that could be interpreted meaningfully in two ways (Bransford & Johnson, 1973). It could be viewed as being either about watching a peace march from the 40th floor of a building or about a space trip to an inhabited planet. Participants omitted different details, depending on what they thought the passage was about. Consider, for example, a sentence mentioning that the atmosphere did not require the wearing of special clothing. Participants were more likely to remember it when they thought the passage was about a trip into outer space than when they thought it was about a peace march.

Consider a comparable demonstration in a different domain (Bower, Karlin, & Dueck, 1975). Investigators showed participants 28 different *droodles*—nonsense pictures that can be given various interpretations (see also Chapter 10). Half of the participants in their experiment were given an interpretation by which they could label what they saw. The other half did not receive an interpretation prompting a label. Participants in the label group correctly reproduced almost 20% more droodles than did participants in the control group. In the upcoming sections, we will consider in more detail autobiographical memory, memory distortions, and the effects of context on our memory.

Autobiographical Memory

Autobiographical memory refers to memory of an individual's history. Autobiographical memory is constructive. One remembers one's construction or reconstruction of what happened rather than exactly what happened. People's autobiographical memories are generally quite good. Nevertheless, they are subject to distortions (as will be discussed later). They are differentially good for different periods of life. Middle-aged adults often remember events from their youthful and early adult periods better than they remember events from their more recent past (Read & Connolly, 2007; Rubin, 1982, 1996).

One way of studying autobiographical memory is through diary studies. In such studies, individuals, often researchers, keep detailed autobiographies (e.g., Linton, 1982; Wagenaar, 1986). One investigator, for example, kept a diary for a 6-year period

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(Linton, 1982). She recorded at least two experiences per day on index cards. Then, each month she chose two cards at random and tried to recall the events she had written on the cards as well as the dates of the events. She further rated each memory for its salience and its emotional content. Surprisingly, her rate of forgetting of events was linear. It was not curvilinear, as is usually the case. In other words, a typical memory curve shows substantial forgetting over short time intervals and then a slowing in the rate of forgetting over longer time intervals. Linton's forgetting curve, however, did not show any such pattern. Her rate of forgetting was about the same over the entire 6-year interval. She also found little relationship between her ratings of the significance and emotionality of memories, on the one hand, and their memorability, on the other. Thus, she surprised herself in what she did and did not remember.

In another study of autobiographical memory, a researcher attempted to recall information regarding performances attended at the Metropolitan Opera over a period of 25 years (Sehulster, 1989). The study data comprised a total of 284 performances. The results were more in line with traditional expectations. Operas seen near the beginning and end of the 25-year period were remembered better (serial-position effect). Important performances also were better recalled than less important ones.

Recent work has illustrated the importance of self-esteem in the formation and recall of autobiographical memory. People with positive self-esteem remember more positive events, whereas people with negative self-esteem remember more negative events (Christensen, Wood, & Barrett, 2003). Likewise, depressed people recall more negative memories than people who are not depressed (Wisco & Nolen-Hoeksema, 2009). When people misremember, they usually tend to be wrong with regard to minor and marginal aspects, but they remember the central characteristics correctly. But if you think about it, this is not so surprising. If we would remember a large number of small details, those

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Events like the attacks of September 11, 2001, are often remembered in flashbulb memories that are experienced almost as vividly as a movie.

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details would likely at some point start to interfere with our memories for important things. So it may be better to concentrate on what is really important (Bjork, Bjork, & MacLeod, 2005; Goldsmith et al., 2005).

An often-studied form of vivid memory is the **flashbulb memory**—a memory of an event so powerful that the person remembers the event as vividly as if it were indelibly preserved on film (Brown & Kulik, 1977). People old enough to recall the assassination of President John Kennedy may have flashbulb memories of this event. Some people also have flashbulb memories for the destruction of the World Trade Center, or momentous events in their personal lives. The emotional intensity of an experience may enhance the likelihood that we will recall the particular experience (over other experiences) ardently and perhaps accurately (Bohannon, 1988). A related view is that a memory is most likely to become a flashbulb memory under three circumstances: The memory trace is important to the individual, is surprising, and has an emotional effect on the individual (Conway, 1995).

Some investigators suggest that flashbulb memories may be more vividly recalled because of their emotional intensity. Other investigators, however, suggest that the vividness of recall may be the result of the effects of rehearsal. The idea is that we frequently retell, or at least silently contemplate, our experiences of these momentous events. Perhaps our retelling also enhances the perceptual intensity of our recall (Bohannon, 1988). Other findings suggest that flashbulb memories may be perceptually rich (Neisser & Harsch, 1993). In this view, they may be recalled with relatively greater confidence in the accuracy of the memories (Weaver, 1993) but not actually be any more reliable or accurate than any other recollected memory (Neisser & Harsch, 1993; Weaver, 1993). Suppose flashbulb memories are indeed more likely to be the subject of conversation or even silent reflection. Then perhaps, at each retelling of the experience, we reorganize and construct our memories such that the accuracy of our recall actually diminishes, while the perceived vividness of recall increases over time.

A study examining the memories of more than 3,000 people of the September 11 attacks on the World Trade Center towers in New York City found that the rate of forgetting is faster in the first year and then slows down. This change in rate allows the content to become more stable later on. Furthermore, it seems that emotional reactions elicited by the flashbulb memories are not as well remembered as nonemotional features, such as where a person was at the time of the attack (Hirst et al., 2009).

A study by Talarico and Rubin (2003) also used the September 11 attacks to examine flashbulb memory. Participants wrote down details about the attacks as well as other everyday life events that happened in the days just before the attacks. Then participants were asked to recall details about the everyday event and the attacks either 1, 6, or 32 weeks after they first wrote down their accounts. The researchers found that there was little difference in terms of how detailed the memories of the everyday event and flashbulb memory were and how many errors were made in remembering these events. Participants, however, had much more doubt about the correctness of their memories of the everyday experience than of their flashbulb memories, indicating that people experience their flashbulb memories much more vividly than other memories. This leads them to believe the flashbulb memories are more accurate, even if they are not.

In a more recent experiment, Michael Jackson's death was examined as an occasion for the formation of flashbulb memories. Researchers found that people's feelings of bonding with Jackson predicted their confidence in the correctness of their flashbulb memories 18 months later, but it did not predict the degree of correctness of their memories (Day & Ross, 2014).

Some interesting effects of flashbulb memory involve the role of emotion. The more a person is emotionally involved in an event, the better the person's memory is for that

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BELIEVE IT OR NOT Caught in the Past!?

Have you ever been haunted by memories from your past? In a unique case of extraordinary autobiographical memory, a young woman named A. J. is able to recall the date and weekday of every day since she was 14 years old, as well as what she did that day. Conversations with other people, things she sees, and just about everything provides a cue for her to retrieve another memory from her past. She cannot let go of her memories and is caught thinking about it time and again while trying to live her life in the present. However, A. J. does not know how she retrieves her memories; she just "knows" what happened on any particular day in her life.

Researchers have examined her extraordinary ability and found that her superior memory is constrained to autobiographical events—she never was a particularly great student and does not fare well on memory tasks that ask her to recall word lists, for example. It is hypothesized she may have a rare neurodevelopmental, frontostriatal disorder that is related to other disorders like autism, schizophrenia, and attention deficit hyperactivity disorder. But whatever it is that distinguishes A. J. from the rest of us, it seems like for the foreseeable future she'll just have to keep remembering (Parker, Cahill, & McGaugh, 2006).

event. Also, over time, memory for the event degrades (Smith, Bibi, & Sheard, 2004). In one study, more than 70% of people who were questioned about the World Trade Center attacks on September 11, 2001, reported seeing the first plane hit the first tower. This footage, however, was not available until the next day (Pezdek, 2003, 2006). These distortions illustrate the constructive nature of flashbulb memories. These findings further indicate that flashbulb memories are not immune to distortion, as once was thought. Most research on flashbulb memories has been done in connection with negative events, but surprising positive events have the power to produce vivid flashbulb memories as well (Kraha & Boals, 2014).

Are different memory processes at work for flashbulb memories than for other kinds of memories? It appears not. Just as for other memories, the factors that influence encoding and retrieval are ones such as elaboration and the frequency of rehearsal (Neisser, 2003; Read & Connolly, 2007).

Which parts of the brain are involved in autobiographic memories? It seems that the medial temporal lobe is crucially involved in the recall of autobiographic memories. People with lesions in this area have trouble recalling memories from their recent past (but not from their more remote past; Kirwan et al., 2008).

Memory Distortions

People tend to distort their memories (Aminoff, Schacter, & Bar, 2008; Roediger & McDermott, 2000; Schacter & Curran, 2000; Schnider, 2008). For example, just saying something has happened to you makes you more likely to think it really happened. This is true whether the event happened or not (Ackil & Zaragoza, 1998). These distortions tend to occur in seven specific ways, which Schacter (2001) refers to as the "seven sins of memory." Here are his seven sins:

1. *Transience:* Memory fades quickly. For example, although most people know that O. J. Simpson was acquitted of criminal charges in the murder of his wife, they do not remember how they found out about his acquittal. At one time they could have said, but they no longer can.
2. *Absent-mindedness:* People sometimes brush their teeth after already having brushed them or enter a room looking for something only to discover that they have forgotten what they were seeking.

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3. *Blocking:* People sometimes have something that they know they should remember, but they can't. It's as though the information is on the tip of their tongue, but they cannot retrieve it (see also the explanation of the tip-of-the-tongue phenomenon in Chapter 4). For example, people may see someone they know, but the person's name escapes them; or they may try to think of a synonym for a word, knowing that there is an obvious synonym, but are unable to recall it.
4. *Misattribution:* People often cannot remember where they heard what they heard or read what they read. Sometimes people think they saw things they did not see or heard things they did not hear. For example, eyewitness testimony is sometimes clouded by what we think we should have seen, rather than what we actually saw.
5. *Suggestibility:* People are susceptible to suggestion, so if it is suggested to them that they saw something, they may think they remember seeing it. For example, in one study, when asked whether they had seen a television film of a plane crashing into an apartment building, many people said they had seen it. There was no such film.
6. *Bias:* People often are biased in their recall. For example, people who currently are experiencing chronic pain in their lives are more likely to remember pain in the past, whether or not they actually experienced it. People who are not experiencing such pain are less likely to recall pain in the past, again with little regard to their actual past experience.
7. *Persistence:* People sometimes remember things as consequential that, in a broad context, are inconsequential. For example, someone with many successes but one notable failure may remember the single failure better than the many successes.

What are some of the specific ways in which memory distortions are studied? We will consider two research areas next that investigate eyewitness testimony and repressed memories.

The Eyewitness Testimony Paradigm

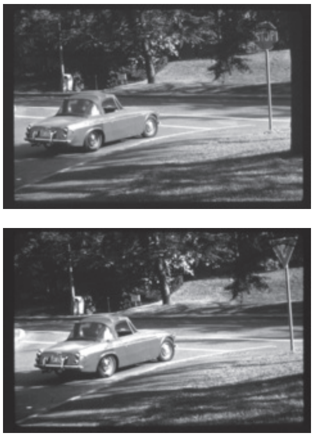
A survey of U.S. prosecutors estimated that about 77,000 suspects are arrested each year after being identified by eyewitnesses (Dolan, 1995). Of the first 180 cases in the United States in which convicts were exonerated through the use of DNA evidence, more than three-quarters involved eyewitness errors (Wells, Memon, & Penrod, 2006).

Eyewitness testimony may be the most common source of wrongful convictions in the United States (Modafferi et al., 2009). Generally, what proportion of eyewitness identifications are mistaken? The answer to that question varies widely ("from as low as a few percent to greater than 90%"; Wells, 1993, p. 554), but even the most conservative estimates of this proportion suggest frightening possibilities.

Consider the story of a man named Timothy. In 1986, Timothy was convicted of brutally murdering a mother and her two young daughters (Dolan, 1995). He was then sentenced to die, and for 2 years and 4 months, Timothy lived on death row. Although the physical evidence did not point to Timothy, eyewitness testimony placed him near the scene of the crime at the time of the murder. Subsequently, it was discovered that a man who looked like Timothy was a frequent visitor to the neighborhood of the murder victims. Timothy received a second trial and was acquitted.

What Influences the Accuracy of Eyewitness Testimonies? The use of eyewitness testimony as the sole, or even the primary, basis for convicting accused people of crimes presents serious potential problems of wrongful conviction (Loftus & Ketcham, 1991; Loftus, Miller, & Burns, 1987; Wells & Loftus, 1984). Moreover, eyewitness testimony is often a powerful determinant of whether a jury will convict an accused person. The effect is particularly pronounced if eyewitnesses appear highly confident of their testimony. This is true even if the eyewitnesses can provide few perceptual details or offer apparently conflicting responses. People sometimes even think they remember things simply because they have imagined or thought about them (Garry & Loftus, 1994). It has been estimated that as many as 10,000 people per year may be convicted wrongfully on the basis of mistaken eyewitness testimony (Cutler & Penrod, 1995; Loftus & Ketcham, 1991). In general, people are remarkably susceptible to mistakes in eyewitness testimony. They are generally prone to imagine that they have seen things they have not seen (Loftus, 1998).

Some of the strongest evidence for the constructive nature of memory has been obtained by those who have studied the validity of eyewitness testimony. In a now-classic study, participants saw a series of 30 slides in which a red Datsun drove down a street, stopped at a stop sign, turned right, and then appeared to knock down a pedestrian crossing at a crosswalk (Loftus, Miller, & Burns, 1978). Afterward, participants were asked a series of 20 questions, one of which referred either to correct information (the stop sign) or incorrect information (a yield sign instead of the stop sign). In other words, the information in the question given this second group was inconsistent with what the participants had seen. Later, after engaging in an unrelated activity, all participants were shown two slides and asked which they had seen. One had a stop sign, the other had a yield sign. Accuracy on this task was 34% better for participants who had received the consistent question (stop sign question) than for participants who had received the inconsistent question (yield sign question).



These are two slides that were shown to participants in the experiment of Loftus and colleagues (1978). Although the slides depicting the initial incident had featured a stop sign, participants who had been questioned about a yield sign often remembered having seen that yield sign in the original scene.

Source: From Loftus, E. F., Miller, D. G., & Burns, H. J. (1978). Semantic integration of verbal information into a visual memory. *Journal of Experimental Psychology: Human Learning and Memory, 4,* 19–31.

Loftus's eyewitness testimony experiment and other experiments (e.g., Loftus, 1975, 1977) have shown people's great susceptibility to distortion in eyewitness accounts. This distortion may be due, in part, to phenomena other than just constructive memory. But it does show that we easily can be led to construct a memory that is different from what really happened. As an example, you might have had a disagreement with a roommate or a friend regarding an experience in which both of you were in the same place at the same time. But what each of you remembers about the experience may differ sharply. And *both* of you may feel that you are truthfully and accurately recalling what happened.

Questions do not have to be suggestive to influence the accuracy of eyewitness testimony. Lineups also can lead to faulty conclusions (Wells, 1993). Eyewitnesses assume that the perpetrator is in the lineup. This is not always the case, however. When the perpetrator of a staged crime was not in a lineup, participants were susceptible to naming someone other than the true perpetrator as the perpetrator. In this way, they believed they were able to recognize *someone* in the lineup as having committed the crime. The identities of the nonperpetrators in the lineup also can affect judgments (Wells, Luus, & Windschitl, 1994). In other words, whether a given person is identified as a perpetrator can be influenced simply by who the others are in the lineup. So the choice of the "distracter" individuals is important. Police inadvertently may affect the likelihood of whether or not an identification occurs and also whether a false identification is likely to occur.

Confessions also influence the testimony of eyewitnesses. A study by Hasel and Kassin (2009) had participants view a staged robbery. Afterward, the participants were presented with a lineup of suspects and were given the opportunity to identify the robber (although the actual perpetrator was not among them). Some time later, the participants were informed that one of the suspects in the lineup had made a confession. In all, 61% of those who had made a selection previously changed their identifications, and 50%

of those who had not made an identification went on to positively identify the confessor. This finding shows what a grave impact a confession has on the identification of a perpetrator.

Likewise, feedback to eyewitnesses affected participants' testimony. Telling them that they had identified the perpetrator made them feel more secure in their choice, whereas the feedback that they had identified a filler person made them back away from their judgment immediately. This phenomenon is called *the postidentification feedback effect* (Wells, 2008; Wright & Skagerberg, 2007).

Eyewitness identification is particularly weak when identifying people of a racial or ethnic group other than that of the witness (e.g., Bothwell, Brigham, & Malpass, 1989; Brigham & Malpass, 1985; Pezdek, Blandon-Gitlin, & Moore, 2003; Shapiro & Penrod, 1986). Evidence suggests that this weakness is not a problem remembering stored faces of people from other racial or ethnic groups, but rather, a problem of accurately encoding their faces (Walker & Tanaka, 2003). Eyewitness identification and recall also are affected by the witness's level of stress. As stress increases, the accuracy of both recall and identification declines (Deffenbacher et al., 2004; Payne et al., 2002). These findings further call into question the accuracy of eyewitness testimony because most crimes occur in highly stressful situations.

Interestingly, when confronted with eyewitness testimony, people tend to give more credence to accounts that have been repeated, no matter whether the account is from just one witness or from several witnesses (Foster et al., 2012).

In another experiment, participants watched a movie in which money (either $5 or $500) was stolen from a student. For half the videos, the video also featured a change-blindness manipulation (see Chapter 3), whereby the perpetrator was replaced by another person halfway through the video. Change blindness increased the wrong identification of the perpetrator in a later lineup from 29% to 58%. Obviously, this decrease in accuracy can be a serious problem when crimes are perpetrated and an innocent person suddenly appears where the perpetrator had been before. The innocent person may be confused with the guilty one. The study also showed, however, that eyewitness identification was more accurate for the severe crime ($500 stolen) than for the less severe crime, indicating that participants paid more attention when they saw the larger amount of money being stolen (Nelson et al., 2011).

Not everyone views eyewitness testimony with such skepticism, however (e.g., see Zaragoza, McCloskey, & Jamis, 1987). It is still not clear whether the information about the original event actually is displaced by, or is simply competing with, the subsequent misleading information. Some investigators have argued that psychologists need to know a great deal more about the circumstances that impair eyewitness testimony before impugning such testimony before a jury (McKenna, Treadway, & McCloskey, 1992).

There is no ultimate verdict yet on eyewitness testimony, but it is certainly important for all involved parties to know the limits of eyewitness statements. Research has shown, however, that although defense attorneys are moderately knowledgeable about the limitations of eyewitness testimony, prosecutors are less so. Indeed, prosecutors tend to overestimate the reliability of eyewitnesses' statements and to underestimate the role of eyewitness statements in wrongful convictions (Wise et al., 2009). These results show the importance of educating the public as well as the parties involved in court proceedings about the fallibility of eyewitness accounts.

Children as Eyewitnesses Whatever may be the validity of eyewitness testimony for adults, it clearly is suspect for children (Ceci & Bruck, 1993, 1995). Children's recollections are particularly susceptible to distortion. Such distortion is especially likely when the children are asked leading questions, as in a courtroom setting.

Consider some relevant facts (Ceci & Bruck, 1995). First, the younger the child is, the less reliable the testimony of that child can be expected to be. In particular, children of preschool age are much more susceptible to suggestive questioning that tries to steer them to a certain response than are school-age children or adults.

Second, when a questioner is coercive or even just seems to want a particular answer, children can be quite susceptible to providing the adult with what he or she wants to hear. Given the pressures involved in court cases, such forms of questioning may be unfortunately prevalent. For instance, when asked a yes-or-no question, even if they don't know the answer, most children will give an answer. If the question has an explicit "I don't know" option, most children, when they do not know an answer, will admit they do not know, rather than speculate (Waterman, Blades, & Spencer, 2001).

in the lab of **ELIZABETH LOFTUS**

Research on False Memories

Remember the time when you were a kid and your family went to Disneyland? The highlight of your trip was meeting Mickey Mouse, who shook your hand?

Remember that? Marketers use autobiographical advertising like this to create nostalgia for their products. Several years ago, we wondered whether such referencing could cause people to believe that they had experiences as children that are mentioned in the ads (Braun, Ellis, & Loftus, 2002). In one study, participants viewed an ad for Disney that suggested that as a child they shook hands with Mickey Mouse. Later on they answered questions about their childhood experiences at Disney. Relative to controls, the ad increased their confidence that as a child they personally had shaken hands with Mickey at Disney.

Courtesy of the author

Elizabeth Loftus

A question came up as to whether the ad caused (1) a revival of a true memory, or (2) the creation of a new, false one. Because some people could have actually met Mickey at Disney, both are possibilities. So, we conducted another study in which people viewed a fake ad for Disney that suggested that they shook hands with an impossible character: Bugs Bunny. Of course, Bugs, a Warner Brothers character, would not be found at a Disney resort. Again, relative to controls, the ad increased confidence that they personally had shaken hands with the impossible character as a child at Disney. Although this could not possibly have happened because Bugs Bunny is a Warner Brothers character and would not be hanging around a Disney property, about 16% of the subjects later said that this actually had happened to them. Many participants will freely supply details about this impossible experience such as remembering that they touched the ear or tail of Bugs or heard him say, "What's up Doc?"

It's one thing to plant a false memory of meeting Bugs Bunny, but quite another to plant a false memory of an unpleasant experience with another character. So in another study we planted a false belief that people had had an unpleasant experience with the Pluto character while on a childhood trip to Disney (Berkowitz et al., 2008). We succeeded with about 30% of the subjects. Moreover, those who were seduced by the suggestion did not want to pay as much for a Pluto souvenir. This finding shows that false beliefs can have consequences that can affect later thoughts and behaviors.

A host of other studies show that false memories have repercussions, meaning they can influence our later thoughts, intentions, or behaviors. For example, we have shown that by planting false memories for food-related experiences (e.g., becoming ill after eating egg salad), we can affect how much people like particular foods and how much they actually eat (Bernstein & Loftus 2009; Bernstein, Scoboria, & Arnold, 2015). We've even been able to do this with alcohol: When we planted a false memory that you got sick as a teenager drinking vodka, people became less interested in drinking a vodka drink (Clifasefi et al., 2013).

These studies are part of a larger program of research on the malleability of human memory (Loftus, 2005). More specifically, they suggest that advertisements or other suggestive influences can tamper with our personal childhood memories. After decades of watching how easy it is to tamper with memory, I can't help but wonder how much of our vast store of memories reflects genuine experience, and how much is a product of suggestion, imagination, or some other mental process?

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Third, children may believe that they recall observing things that others have said they observed. In other words, they hear a story about something that took place and then believe that they have observed what allegedly took place. If the child has some intellectual disability, memory for the event is even more likely to be distorted, at least when a significant delay has occurred between the time of the event and the time of recall (Henry & Gudjonsson, 2003).

A study in the United Kingdom has found that, when giving eyewitness testimony, children are easily impressed by the presence of uniformed officers. When having to identify an individual in a lineup after having witnessed a staged incident, children made significantly more mistakes when a uniformed official was present (Lowenstein, Blank, & Sauer, 2010). Therefore, perhaps even more so than the eyewitness testimony of adults, the testimony of children must be interpreted with great caution.

Can Eyewitness Testimonies Be Improved? Steps can be taken to enhance eyewitness identification (e.g., using methods to reduce potential biases, to reduce the pressure to choose a suspect from a limited set of options, and to ensure that each member of an array of suspects fits the description given by the eyewitness, yet offers diversity in other ways; described in Wells, 1993). Moreover, suggestive interviews can cause biases in memory (Melnyk & Bruck, 2004). This problem is especially likely to occur when these interviews take place close in time to the actual event. After a crime, witnesses generally are interviewed as soon as possible. Therefore, steps must be taken to ensure that the questions asked of witnesses are not leading questions, especially when the witness is a child. This caution can decrease the likelihood of distortion of memory.

Gary Wells (2006) made several suggestions to improve identification accuracy in lineups. These suggestions include presenting only one suspect per lineup so that witnesses do not feel like they have to decide among several people they saw; ensuring that all people in the lineup are reasonably similar to each other to decrease the chance that somebody is identified mistakenly, just because he or she happens to share one characteristic with the suspected perpetrator that no one else in the lineup shares; and cautioning witnesses that the suspect may not be in the lineup at all.

In addition, some psychologists (e.g., Loftus, 1993a, 1993b) and many defense attorneys believe that jurors should be advised that the degree to which the eyewitness feels confident of her or his identification does not necessarily correspond to the degree to which the eyewitness is actually accurate in her or his identification of the defendant as being the culprit. At the same time, some psychologists (e.g., Egeth, 1993; Yuille, 1993) and many prosecutors believe that the existing evidence, based largely on simulated eyewitness studies rather than on actual eyewitness accounts, is not strong enough to risk attacking the credibility of eyewitness testimony when such testimony might send a true criminal to prison, preventing the person from committing further crimes.

Repressed Memories

Might you have been exposed to a traumatic event as a child but have been so traumatized by this event that you now cannot remember it? Some psychotherapists have begun using hypnosis and related techniques to elicit from people what are alleged to be repressed memories. *Repressed memories* are memories that are alleged to have been pushed down into unconsciousness because of the distress they cause. Such memories, according to the view of psychologists who believe in their existence, are inaccessible, but they can be dredged up (Briere & Conte, 1993). Although people may be able to forget terrible events that happened to them, the support is only dubious for the notion that clients in psychotherapy often are unaware of their having been abused as a child (Loftus, 1996).

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"First, we'll look for repressed memories of malpractice suits."

Published in *The New Yorker*, December 1, 1997, Frank Cotham/www.Cartoonbank.com

Do repressed memories actually exist? Many psychologists strongly doubt their existence (Ceci & Loftus, 1994; Roediger & McDermott, 1995, 2000; Patihis et al., 2014). Others are at least highly skeptical (Bowers & Farvolden, 1996; Brenneis, 2000). There are many reasons for this skepticism. First, some therapists may inadvertently plant ideas in their clients' heads. In this way, they may create false memories of events that never took place. Indeed, creating false memories is relatively easy, even in people with no particular psychological problems. Such memories can be implanted by using ordinary, nonemotional stimuli (see below; Roediger & McDermott, 1995). Second, showing that implanted memories are false is often extremely hard to do. Reported incidents often end up, as in the case of childhood sexual abuse, merely pitting one person's word against another (Schooler, 1994). At the present time, no compelling evidence points to the existence of such memories. But psychologists also have not reached the point at which their existence can be ruled out definitively. Therefore, no clear conclusion can be reached at this time.

The Roediger–McDermott (1995) paradigm, which is adapted from the work of Deese (1959), is able to show the effects of memory distortion in the laboratory. Participants receive a list of 15 words strongly associated with a critical but nonpresented word. For example, the participants might receive 15 words strongly related to the word *sleep* but never receive the word *sleep*. The recognition rate for the nonpresented word (in this case, *sleep*) was comparable to that for presented words. This result has been replicated multiple times (McDermott, 1996; Schacter, Verfaellie, & Pradere, 1996; Sugrue & Hayne, 2006). Even when shorter lists were used, the level of false recognition increased

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for nonpresented items. In one experiment, lists as short as three items revealed this effect, although to a lesser degree (Coane et al., 2007). Embedding the list in a story can increase this effect in young children. This strategy strengthens the shared context and increases the probability of a participant's falsely recognizing the nonpresented word (Dewhurst, Pursglove, & Lewis, 2007).

Why are people so weak in distinguishing what they have heard from what they have not heard? One possibility is a *source-monitoring error,* which occurs when a person attributes a memory derived from one source to another source. People frequently have difficulties in *source monitoring,* or figuring out the origins of a memory. They may believe they read an article in a prestigious newspaper, such as *The New York Times,* when in fact they saw it in a tabloid on a supermarket shelf while waiting to check out. When people hear a list of words not containing a word that is highly associated with the other words, they may believe that their recall of that central word is from the list rather than from their minds (Foley et al., 2006; Johnson, 1996, 2002).

Another possible explanation of this increased false recognition is *spreading activation*. In spreading activation, every time an item is studied, you think of the items related to that item. Imagine a metaphorical spider web with a word in the middle. Branching out from that word are all the words relating to that word. In addition to individual differences in the construction of these webs, there also will be a lot of overlap. For instance, when you read the word *nap,* words like *sleep, bed,* and *cat* may be activated in your mind. In this way, activation branches out from the original word *nap.* If you see 15 words, all of which activate the word *sleep,* it is likely that, via a source-monitoring error, you may think you had been presented the word *sleep.* Some recent work supports the spreading-activation theory of errors in this paradigm (Dodd & MacLeod, 2004; Hancock et al., 2003; Roediger, Balota, & Watson, 2001). This theory is not, however, universally accepted (Meade et al., 2007). ■ To further explore repressed memories, go to Lab 34, Forgot-It-All-Along, in CogLab.

The Effect of Context on Memory

A number of factors, such as emotions, moods, states of consciousness, schemas, and other features of our internal context, clearly affect memory retrieval. As studies of constructive memory show, our cognitive contexts for memory clearly influence our memory processes of encoding, storing, and retrieving information. Studies of expertise also show how existing schemas (frameworks for representing knowledge; see also Chapter 8) may provide a cognitive context for encoding, storing, and retrieving new information. Specifically, experts generally have more elaborated schemas than do novices in regard to their areas of expertise (e.g., Chase & Simon, 1973; Frensch & Sternberg, 1989). These schemas provide a cognitive context in which the experts can operate. The use of schemas makes integration and organization relatively easy. They fill in gaps when provided with partial or even distorted information and visualize concrete aspects of verbal information. They also can implement appropriate metacognitive strategies for organizing and rehearsing new information. Clearly, expertise enhances our confidence in our recollected memories.

Our moods and states of consciousness also may provide a context for encoding that affects later retrieval of semantic memories. Thus, when we encode semantic information during a particular mood or state of consciousness, we may more readily retrieve that information when in the same state again (Baddeley, 1989; Bower, 1983). Interestingly, an Australian study has found that weather-induced negative mood improves people's memory for everyday scenes (like a scene in a shopping mall; Forgas, Goldenberg, & Unkelbach, 2009).

How does state of consciousness affect memory? Something that is encoded when we are influenced by alcohol or other drugs may be retrieved more readily while under those same influences again (Eich, 1980, 1995). On the whole, however, the "main effect" of alcohol and many drugs is stronger than the interaction: The depressing effect of alcohol and many drugs on memory is greater than the facilitating effect of recalling something in the same drugged state as when one encoded it.

Some investigators have suggested that people in a depressed mood can more readily retrieve memories of previous sad experiences, which may further the continuation of the depression (Baddeley, 1989; see also Wisco & Nolen-Hoeksema, 2009). If psychologists or others can intervene to prevent the continuation of this vicious cycle, the person may begin to feel happier. As a result, other happy memories may be more easily retrieved, thus further relieving the depression, and so on. Perhaps the folk wisdom advice to "think happy thoughts" is not entirely unfounded. In fact, under laboratory conditions, participants seem more accurately to recall items that have pleasant associations than they recall items that have unpleasant or neutral associations (Matlin & Underhill, 1979; Monnier & Syssau, 2008). Interestingly, people suffering from depression tend to have deficits in forming and recalling memories (Bearden et al., 2006).

Even our external contexts may affect our ability to recall information. We appear to be better able to recall information when we are in the same physical context as the one in which we learned the material (Godden & Baddeley, 1975). In one experiment, 16 underwater divers were asked to learn a list of 40 unrelated words. Learning occurred either while the divers were on shore or while they were 20 feet beneath the sea. Later, they were asked to recall the words when either in the same environment as where they had learned them or in the other environment. Recall was better when it occurred in the same place as did the learning.

Even infants demonstrate context effects on memory. Consider an operant-conditioning experiment in which the infants could make a crib mobile move in interesting ways by kicking it. Three-month-old infants (Butler & Rovee-Collier, 1989) and 6-month-old infants (Borovsky & Rovee-Collier, 1990) were given an opportunity to kick a distinctive crib mobile in the same context (i.e., surrounded by a distinctive bumper lining the periphery of the crib) in which they first learned to kick it or in a different context. They kicked more strongly in the same context. The infants showed much less kicking when in a different context or when presented with a different mobile.

From these results, such learning seems highly context-dependent. In one set of studies, however, 3-month-old infants (Rovee-Collier & DuFault, 1991) and 6-month-old infants (Amabile & Rovee-Collier, 1991) were offered operant-conditioning experiences in multiple contexts for kicking a distinctive mobile. Soon thereafter, they were placed in a novel context. It was unlike any of the contexts for conditioning. The infants retained the memory. They kicked the mobile at high rates in the novel context. Thus, when information is encoded in various contexts, the information also seems to be retrieved more readily in various contexts. This effect occurs at least when there is minimal delay between the conditioning contexts and the novel context. Consider, however, what happened when the novel context occurred after a long delay. The infants did not show increased kicking. Nevertheless, they still showed context-dependent memory for kicking in the familiar contexts (Amabile & Rovee-Collier, 1991).

All of the preceding context effects may be viewed as an interaction between the context for encoding and the context for retrieval of encoded information. The results of various experiments on retrieval suggest that how items are encoded has a strong effect both on how, and on how well, items are retrieved. This relationship is called **encoding specificity**—what is recalled depends on what is encoded (Tulving & Thomson, 1973).

Marian and Fausey (2006) were interested in studying bilingual Spanish–English speakers. Participants in the study were presented with four short stories about topics from the areas of mythology, history, biology, and chemistry. Two of the stories were presented in English and two were presented in Spanish. After listening to these stories, the participants had to answer questions relating to stories. Again, half of those questions were asked in English whereas half of them were asked in Spanish. Participants had to answer each question in the language in which the question had been asked. Participants remembered facts more accurately when the language in which they answered the questions was the language in which they had learned the facts. That is, their answers were more accurate for content that had been learned in English and had been asked about in English or learned and asked about in Spanish.

You may recall the levels-of-processing approach we discussed in Chapter 5. We stated that information that was processed at a deeper level also was recalled at a higher level. This principle can be overridden by the principle of encoding specificity, however. Information that was encoded only at a shallow level still may be recalled easily when the context in which it was learned is similar to the context in which it is being retrieved.

Consider a rather dramatic example of encoding specificity. We know that recognition memory is virtually always better than recall. For example, recognizing a word that you have learned is easier than recalling it. After all, in recognition you have only to say whether you have seen the word. In recall, you have to generate the word and then mentally confirm whether it appeared on the list.

In one experiment, Watkins and Tulving (1975) had participants learn a list of 24 paired associates, such as *ground-cold* and *crust-cake.*

- Participants were instructed to learn to associate each response (such as *cold*) with its stimulus word (such as *ground*).
- After participants had studied the word pairs, they were given an irrelevant task.
- Then they were given a recognition test with distracters.
- Participants were asked simply to circle the words they had seen previously.

Participants recognized an average of 60% of the words from the list. Then, participants were provided with the 24 stimulus words. They were asked to recall the responses. Their cued recall was 73%. Thus, recall was better than recognition. Why? According to the encoding-specificity hypothesis, because the words had been learned as paired associates, the stimulus was a better cue for the word than the word itself. ■ Explore encoding specificity further by going to Lab 28, Encoding, in CogLab.

As mentioned in Chapter 5, the link between encoding and retrieval also may explain the *self-reference effect* (Greenwald & Banaji, 1989). Specifically, the main cause of the self-reference effect is not due to unique properties of self-referent cues. Rather, it is due to a more general principle of encoding and retrieval: When individuals generate their own cues for retrieval, they are much more potent than when other individuals do so.

Other researchers have confirmed the importance of making cues meaningful to the individual to enhance memory. For example, consider what happened when participants made up their own retrieval cues. They were able to remember, almost without errors, lists of 500 and 600 words (Mantyla, 1986). For each word on a list, participants were asked to generate another word (the cue) that to them was an appropriate description or property of the target word. Later, they were given a list of their cue words. They were asked to recall the target word. Cues were most helpful when they were both *compatible* with the target word and *distinctive,* in that they would not tend to generate a large number of related words. For example, if you are given the word *coat,* then *jacket* might be both compatible and distinctive as a cue. Suppose, however, you came up with the word *wool* as a cue. That cue might make you think of a number of words, such as *fabric* and *sheep,* which are not the target word.

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To summarize, retrieval interacts strongly with encoding. Suppose you are studying for a test and want to recall well at the time of testing. Organize the information you are studying in a way that appropriately matches the way in which you will be expected to recall it. Similarly, you will recall information better if the level of processing for encoding matches the level of processing for retrieval (Moscovitch & Craik, 1976).

CONCEPT CHECK

1. What is autobiographical memory?
2. In what specific ways do memory distortions occur?
3. Do you think eyewitness accounts should be allowed in court?
4. What are repressed memories?
5. How does the context influence encoding and retrieval of information?

Key Themes

This chapter illustrates several of the key themes first presented in Chapter 1.

Rationalism versus empiricism. To what extent should courts rely on empirical evidence from psychological research to guide what they do? To what extent should the credibility of witnesses be determined by rational considerations (e.g., were they at the scene of a crime, or are they known to be trustworthy) and to what extent by empirical considerations revealed by psychological research (e.g., being at the scene of a crime does not guarantee credible testimony, and people's judgments of trustworthiness are often incorrect)? Court systems often work on the basis of rational considerations—of what should be. Psychological research reveals what is.

Domain generality versus domain specificity. Mnemonics discussed in this chapter work better in certain domains than they do in others. For example, you may be able to devise mnemonics better if you are highly familiar with a domain, such as was the case for the long-distance runner studied by Ericsson, Chase, and Faloon (1980; discussed in Chapter 5). In general, the more knowledge you have about a domain, the easier it will be to chunk information in that domain.

Validity of causal inferences versus ecological validity. Some researchers, such as Mahzarin Banaji and Robert Crowder (1989), have argued that laboratory research yields findings that maximize not only experimental control but also ecological validity. Ulric Neisser has disagreed, suggesting that if one wishes to study everyday memory, one must study it in everyday settings. Ultimately, the two kinds of research together are likely to maximize our understanding of memory phenomena. Typically, there is no one right way to do research. Rather, we learn the most when we use a variety of methods that converge on a set of common findings.

SUMMARY

1. **What have cognitive psychologists discovered regarding how we encode information for storing it in memory?** Encoding of information in short-term memory appears to be largely, although not exclusively, acoustic in form. Information in short-term memory is susceptible to acoustic confusability—that is,

errors based on sounds of words. But there is some visual and semantic encoding of information in short-term memory. Information in long-term memory appears to be encoded primarily in a semantic form. Thus, confusion tends to occur in terms of meanings rather than in terms of the sounds of words. In addition, some evidence points to the existence of visual encoding, as well as of acoustic encoding, in long-term storage.

Transfer of information into long-term storage may be facilitated by several factors:

a. rehearsal of the information, particularly if the information is elaborated meaningfully;
b. organization, such as categorization of the information;
c. the use of mnemonic devices;
d. the use of external memory aids, such as writing lists or taking notes; and
e. knowledge acquisition through distributed practice across various study sessions, rather than through massed practice.

The distribution of time during any given study session does not seem to affect transfer into long-term memory. The effects of distributed practice may be due to a hippocampal-based mechanism that results in rapid encoding of new information to be integrated with existing memory systems over time, perhaps during sleep.

2. **What affects our ability to retrieve information from memory?** Studying retrieval from long-term memory is difficult because of problems of differentiating retrieval from other memory processes.

   It also is difficult to differentiate accessibility from availability. Retrieval of information from short-term memory appears to be in the form of serial exhaustive processing. This implies that a person always sequentially checks all information on a list. Nevertheless, some data may be interpreted as allowing for the possibility of self-terminating serial processing and even of parallel processing.

3. **How does what we know or what we learn affect what we remember?** Two of the main theories of forgetting in short-term memory are decay theory and interference theory. Interference theory distinguishes between retroactive interference and proactive interference. Assessing the effects of decay, while ruling out both interference and rehearsal effects, is much harder. However, some evidence of distinctive decay effects has been found.

   Interference also seems to influence long-term memory, at least during the period of consolidation. This period may continue for several years after the initial memorable experience.

   Memory appears to be not only reconstructive—a reproduction of what was learned, based on recalled data and on inferences from only those data—but also constructive—influenced by attitudes, subsequently acquired information, and schemas based on past knowledge. As shown by the effects of existing schemas on the construction of memory, schemas affect memory processes. So, however, do other internal contextual factors, such as emotional intensity of a memorable experience, mood, and even state of consciousness. In addition, environmental context cues during encoding seem to affect later retrieval. Encoding specificity refers to the fact that what is recalled depends largely on what is encoded. How information is encoded at the time of learning will greatly affect how it is later recalled.

   One of the most effective means of enhancing recall is for the individual to generate meaningful cues for subsequent retrieval.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. In what forms do we encode information for brief memory storage versus long-term memory storage?
2. What is the evidence for encoding specificity? Cite at least three sources of supporting evidence.
3. What is the main difference between two of the proposed mechanisms by which we forget information?
4. Compare and contrast some of the views regarding flashbulb memory.
5. Suppose that you are an attorney defending a client who is being prosecuted solely on the basis of eyewitness testimony. How could you demonstrate to members of the jury the frailty of eyewitness testimony?
6. Use the chapter-opening example from Bransford and Johnson as an illustration to make up a description of a common procedure without labeling the procedure (e.g., baking chocolate chip cookies or changing a tire). Try having someone read your description and then recall the procedure.
7. Make a list of 10 or more unrelated items you need to memorize. Choose one of the mnemonic devices mentioned in this chapter, and describe how you would apply the device to memorizing the list of items. Be specific.
8. What are three things you learned about memory that can help you to learn new information and effectively recall the information over the long term?

KEY TERMS

accessibility, p. 222
autobiographical memory, p. 228
availability, p. 222
consolidation, p. 210
constructive, p. 228
decay, p. 209
decay theory, p. 226
distributed practice, p. 211
encoding, p. 205
encoding specificity, p. 239
flashbulb memory, p. 230
interference, p. 209
interference theory, p. 222
massed practice, p. 211
metacognition, p. 210
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mnemonic devices, p. 214
primacy effect, p. 224
proactive interference, p. 223
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reconstructive, p. 228
rehearsal, p. 210
retrieval (memory), p. 205
retroactive interference, p. 223
schemas, p. 224
serial-position curve, p. 224
spacing effect, p. 211
storage (memory), p. 205

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 20—Brown-Peterson Task
Lab 33—False Memory
Lab 31—Serial Position
Lab 22—Sternberg Search
Lab 32—Von Restorff Effect
Lab 28—Encoding Specificity
Lab 34—Forgot It All Along
Lab 36—Remember-Know

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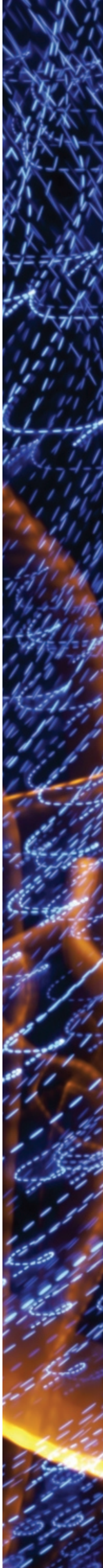
7

Mental Images and Propositions

CHAPTER OUTLINE

- **Mental Representation of Knowledge**
  - Communicating Knowledge: Pictures versus Words
  - Pictures in Your Mind: Mental Imagery
  - Dual-Code Theory: Images and Symbols
  - Storing Knowledge as Abstract Concepts: Propositional Theory
    - What Is a Proposition?
    - Using Propositions
  - Do Propositional Theory and Imagery Hold Up to Their Promises?
    - Limitations of Mental Images
    - Limitations of Propositional Theory
- **Mental Manipulations of Images**
  - Principles of Visual Imagery
  - Neuroscience and Functional Equivalence
  - Mental Rotations
    - How Does Mental Rotation Work?
    - Neuroscience and Mental Rotation
    - Gender and Mental Rotation
  - Zooming in on Mental Images: Image Scaling
  - Examining Objects: Image Scanning
  - Representational Neglect
- **Synthesizing Images and Propositions**
  - Do Experimenters' Expectations Influence Experiment Outcomes?
  - Johnson-Laird's Mental Models
  - Neuroscience: Evidence for Multiple Codes
    - Left Brain or Right Brain: Where Is Information Manipulated?
    - Two Kinds of Images: Visual versus Spatial
- **Spatial Cognition and Cognitive Maps**
  - Of Rats, Bees, Pigeons, and Humans
  - Rules of Thumb for Using Our Mental Maps: Heuristics
  - Creating Maps from What You Hear: Text Maps
- **Key Themes**
- **Summary**
- **Thinking about Thinking: Analytical, Creative, and Practical Questions**
- **Key Terms**
- **Media Resources**

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. What are some of the major hypotheses regarding how knowledge is represented in the mind?
2. What are some of the characteristics of mental imagery?
3. How does knowledge representation benefit from both images and propositions?
4. How may conceptual knowledge and expectancies influence the way we use images?

BELIEVE IT OR NOT

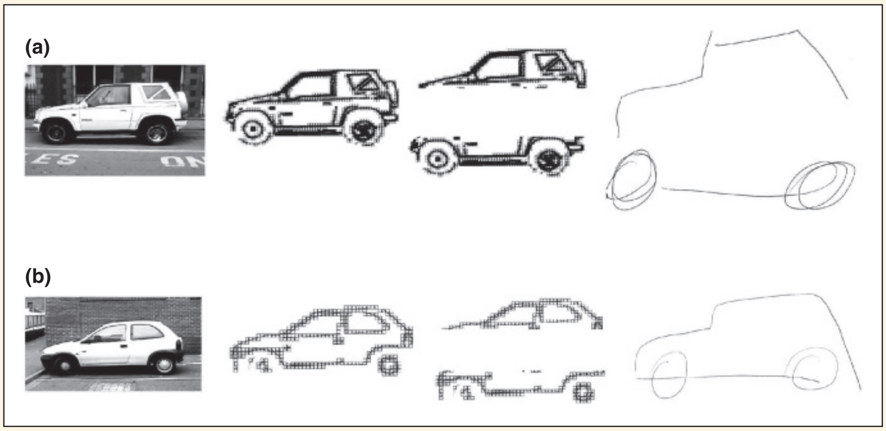
City Maps of Music for the Blind

How can a person who is blind find his or her way around in a new city? Well, not too far in the future they may be able to hear their way around by means of a translation of the landscape into music. Researchers are developing a handheld device that helps blind persons navigate their environment with their ears (Cronly-Dillon, Persaud, & Blore, 2000).

Just like a musical score is made up of black dots in a particular spatial distribution and are then transformed into music by a musician, the pixels in a digital image can be transformed into music as well. Listeners explore the musical landscape and create a mental image of what they see. The picture is read from the left to the right; a horizontal line is played as one continuous note, a vertical line is played as a fast chord of many notes, and a diagonal line from the top left to the bottom right can be heard as a descending scale. Listeners can scan an entire scene or zoom in to see the details of an object. The resulting music sounds a little like modern music. However, this process only works for people who were once able to see because they developed the ability to create three-dimensional (3-D) mental images.

For example, in one study, blind subjects were able to distinguish trees, different buildings (like Victorian or modern houses and churches), or various types of cars. The blind subjects communicated their mental images to the researchers by drawing. In Figure 7.1 ■, you can see the original images of two cars, processed images that were analyzed by the blind subjects, and the pictures of the mental images they drew.

In this chapter, we will explore the representation of knowledge in our minds—in words as well as in images.



■ **Figure 7.1** How People Who Are Blind Form Mental Images.

Source: Cronly-Dillon, J., Persaud, K. C., & Blore, R. (2000). Blind subjects construct conscious mental images of visual scenes encoded in musical form. *Proceedings of the Royal Society B: Biological Sciences, 267,* 2231–2238.

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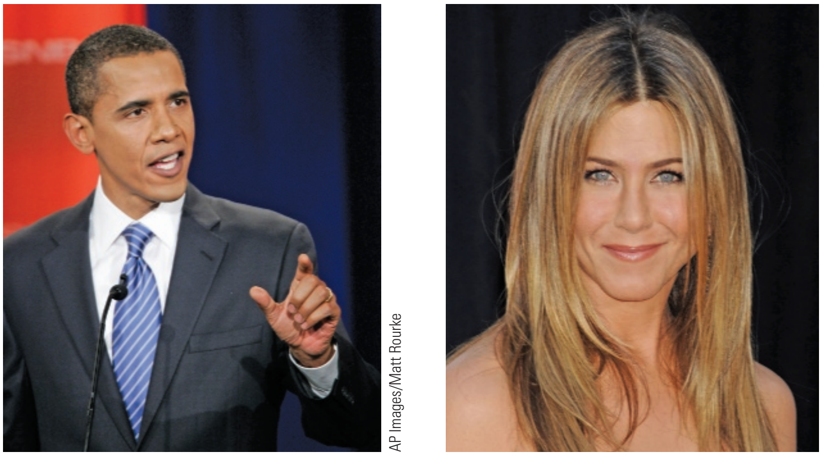

AP Images/Matt Rourke

Pictorial Press Ltd/Alamy

■ **Figure 7.2 Mental Representations.** Look at both of these photos carefully. Next, close your eyes, and picture the people represented—people whom you recognize from reports in the media. Without looking again at the photos, mentally compare the appearances of the two people you have chosen. To compare the people, you need to have a mental representation of them in your mind.

Look carefully at the photos depicted in Figure 7.2 ■. Now cover the photos and describe to yourself what two of these people look like and sound like. Clearly, none of these people can truly exist in a physical form inside your mind. How are you able to imagine and describe them? You must have stored in your mind some form of *mental representation,* something that stands for these people of what you know about them.

What you use to recall these celebrities is more generally called **knowledge representation**, the form for what you know in your mind about things, ideas, events, and so on, in the outside world.

This chapter explores how knowledge is stored and represented in our minds:

- First, we consider what representations are and in what form they can be stored.
- Second, we will look at theories that describe knowledge representation and suggest that we store our knowledge in images, symbols, or propositions.
- Third, we look more closely at images in our mind. How can we rotate or scan them; in short, how can we manipulate mental images?
- Fourth, we examine whether separate theories regarding images and propositions can be combined as one approach.
- Last, we look at mental maps.

Mental Representation of Knowledge

Ideally, cognitive psychologists would directly observe how each of us represents knowledge. It would be like taking a series of snapshots of ongoing knowledge representations in the human mind. Unfortunately, direct empirical methods for observing knowledge representations are not available at present. Such methods are unlikely to be available in the immediate future. Several alternative methods remain, however. We can ask people to describe their own knowledge representations and knowledge representation processes: What do they see in their minds when they think of the Statue of Liberty, for example? Unfortunately, none of us has conscious access to our own knowledge representation processes, and self-reported information about these processes is highly unreliable (Pinker, 1985). Therefore, an introspectionist approach goes only so far.

Another way to observe how we represent knowledge in our minds is the rationalist approach. In this approach, we try to deduce logically how people represent knowledge. For centuries, philosophers have done exactly that. In classic epistemology—the study

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of the nature, origins, and limits of human knowledge—philosophers distinguished between two kinds of knowledge structures. The first type of knowledge structure is **declarative knowledge**. Declarative knowledge refers to facts that can be stated, such as the date of your birth, the name of your best friend, or the way a rabbit looks. **Procedural knowledge** refers to knowledge of procedures that can be implemented. Examples are the steps involved in tying your shoelaces, adding a column of numbers, or driving a car. The distinction is between *knowing that* and *knowing how* (Ryle, 1949). These concepts will be used later in the chapter.

There are two main sources of empirical data on knowledge representation: standard laboratory experiments and neuropsychological studies. In experimental work, researchers indirectly study knowledge representation because they cannot look into people's minds directly. Instead, they observe how people handle various cognitive tasks that require the manipulation of mentally represented knowledge.

In neuropsychological studies, researchers typically use one of two methods: (1) they observe how the normal brain responds to various cognitive tasks involving knowledge representation, or (2) they observe the links between various deficits in knowledge representation and associated pathologies in the brain.

In the following sections, we explore some of the theories researchers have proposed to explain how we represent and store knowledge in our minds:

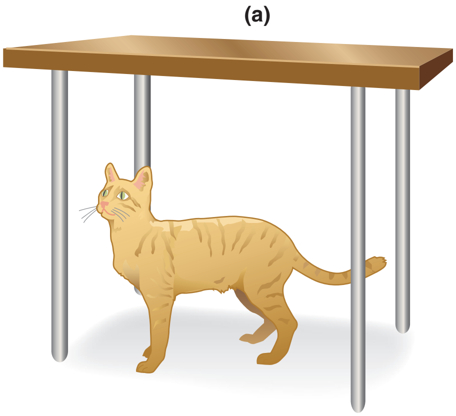
- First, we consider what the difference is between images and words when they are used to represent ideas in the outside world, such as in a book.
- Then we learn about mental images and the idea that we store some of our knowledge in the form of images.
- Next, we explore the idea that knowledge is stored in the form of both words and images (dual-code theory).
- Finally, we consider an alternative—propositional theory—which suggests that we actually use an abstract form of knowledge encoding that makes use of neither words nor mental images.

Communicating Knowledge: Pictures versus Words

Knowledge can be represented in different ways in your mind: It can be stored as a mental picture, or in words, or abstract propositions. In this chapter, we focus on the difference between those kinds of knowledge representation. Of course, cognitive psychologists chiefly are interested in our internal, mental representations of what we know. Before we turn to our internal representations, let's look at external representations, like books. A book communicates ideas through words and pictures. How do external representations in words differ from such representations in pictures?

Some ideas are better and more easily represented in pictures, whereas others are better represented in words. For example, suppose someone asks you, "What is the shape of a chicken egg?" You may find drawing an egg easier than describing it. Many geometric shapes and concrete objects seem easier to represent in pictures rather than in words. However, what if someone asks you, "What is justice?" Describing such an abstract concept in words would already be difficult, but doing so pictorially would be even harder.

As Figure 7.3(a) ■ and Figure 7.3(b) ■ show, both pictures and words may be used to represent things and ideas, but neither form of representation actually retains all the characteristics of what is being represented. For example, neither the word *cat* nor the picture of the cat actually eats fish, meows, or purrs when petted. Both the word *cat* and the picture of this cat are distinctive representations of "catness." Each type of representation has distinctive characteristics.



(b) The cat is under the table.

(c) UNDER (CAT, TABLE)

Figure 7.3 Different Kinds of Mental Representations. We may represent things and ideas in pictures or in words. Neither pictures nor words capture all the characteristics of what they represent, and each more readily captures some kinds of information than other kinds. Some cognitive psychologists have suggested that we have (a) some mental representations that resemble pictorial, analogous images; (b) other mental representations that are highly symbolic, like words; and (c) perhaps even more fundamental propositional representations that are in a pure abstract "mentalese" that is neither verbal nor pictorial, which cognitive psychologists often represent in this highly simplified shorthand.

As you just observed, the picture is relatively *analogous* (i.e., similar) to the real-world object it represents. The picture shows concrete attributes, such as shape and relative size. These attributes are similar to the features and properties of the real-world object the picture represents. Even if you cover up a portion of the figure of the cat, what remains still looks like a part of a cat. Under typical circumstances, most aspects of the picture are grasped simultaneously; but you may scan the picture, zoom in for a closer look, or zoom out to see the big picture. Even when scanning or zooming, however, there are no arbitrary rules for looking at the picture—you may scan the picture from the left to the right, from the bottom to the top, or however it pleases you.

In contrast, the word *cat* is a **symbolic representation**, meaning that the relationship between the word and what it represents is simply arbitrary. The word represents nothing inherently catlike. If you had grown up in another country like Germany or France, the word *Katze* or the word *chat*, respectively, would instead symbolize the concept of a cat to you. Suppose you cover up part of the word *cat*. The remaining visible part no longer bears even a symbolic relationship to any part of a cat.

Because symbols are arbitrary, their use requires the application of rules. For example, in forming words, the sounds or letters also must be sequenced according to rules (e.g., *cat*, not *act* or *tca*). In forming sentences, the words also must be sequenced according to rules. For example, one can say "the cat is under the table," but not "table under cat the is."

Symbolic representations, such as the word *cat,* capture some kinds of information but not other kinds of information. The dictionary defines *cat* as "a carnivorous mammal (*Felis catus*) long domesticated as a pet and for catching rats and mice" (*Merriam-Webster's Online Dictionary*, 2014). Suppose our own mental representations for the meanings of words resemble those of the dictionary. Then the word *cat* connotes an animal that eats meat ("carnivorous"), nurses its young ("mammal"), and so on. This information is abstract and general. It may be applied to any number of specific cats having any fur color or pattern. To represent additional characteristics, we must use additional words, such as *black, Persian,* or *calico.*

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Representations in Pictures and Words

Find a book or magazine with a photo of an animal, plant, or other object (house, car, airplane) and write down the word for that thing. What is the shape of the word? What is the shape of the picture? Cover part of the word and explain how what is left relates to the characteristics of that thing. Now cover part of the picture and explain how what is left relates to the characteristics of that thing.

The picture of the cat does not convey any of the abstract information conveyed by the word regarding what the cat eats, whether it nurses its young, and so on. The picture, however, conveys a great deal of concrete information about this specific cat. For example, it communicates the exact position of the cat's legs, the angle at which we are viewing the cat, the length of the cat's tail, whether both of its eyes are open, and so on.

Pictures and words also represent relationships in different ways. The picture in Figure 7.3(a) shows the spatial relationship between the cat and the table. For any given picture showing a cat and a table, the spatial (positional) relationship (e.g., beside, above, below, behind) will be represented concretely in the picture. In contrast, when using words, we must state spatial relationships between things explicitly by a discrete symbol, such as a preposition ("The cat is *under* the table."). More abstract relationships, however, such as class membership, often are implied by the meanings of the words. Cats are mammals and tables are items of furniture. But abstract relationships rarely are implied through pictures.

To summarize, pictures aptly capture concrete and spatial information in a manner analogous to whatever they represent. They convey all features simultaneously. In general, any rules for creating or understanding pictures pertain to the analogous relationship between the picture and what it represents. They help ensure as much similarity as possible between the picture and the object it represents. Words, on the contrary, handily capture abstract and categorical information in a manner that is symbolic of whatever the words represent. Representations in words usually convey information sequentially. They do so according to arbitrary rules that have little to do with what the words represent. Pictures and words are both well suited to some purposes but not to others. For example, blueprints and identification photos serve different purposes than essays and memos.

Now that we have some preliminary ideas about external representations of knowledge, let's consider internal representations of knowledge. Specifically, how do we represent what we know in our minds? Do we have mental scenarios (pictures) and mental narratives (words)? In subsequent chapters on information processing and language, we discuss symbolic mental representations. In this chapter, we focus on mental imagery.

Pictures in Your Mind: Mental Imagery

Imagery is the mental representation of things that are not currently seen or sensed by the sense organs (Moulton & Kosslyn, 2009; Thomas, 2003). In our minds we often have images for objects, events, and settings. For example, recall one of your first experiences on a college campus. What were some of the sights, sounds, and smells you sensed at that time—cut grass, tall buildings, or tree-lined paths? You do not actually smell the grass and see the buildings, but you still can imagine them. Mental imagery can represent things that you have never experienced. For example, imagine what it would be like to travel down the Amazon River. Mental images may even represent things that do not exist outside the mind of the person creating the image. Imagine how you would look if you had a third eye in the center of your forehead!

Imagery may involve mental representations in any of the sensory modalities, such as hearing, smell, or taste. Imagine the sound of a fire alarm, your favorite song, or your nation's anthem. Now imagine the smell of a rose, of fried bacon, or of an onion. Finally, imagine the taste of a lemon, pickle, or your favorite candy. At least hypothetically, each form of mental representation is subject to investigation (e.g., Kurby, Magliano, & Rapp, 2009; Palmieri et al., 2009; Pecenka & Keller, 2009).

Most research on imagery in cognitive psychology has focused on visual imagery, such as representations of objects or settings that are not presently visible to the eyes. When students kept a diary of their mental images, the students reported many more visual images than auditory, smell, touch, or taste images (Kosslyn et al., 1990). Most of us are more aware of visual imagery than of other forms of imagery.

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Analogical and Symbolic Representations of Cats

To get an intuitive sense of how you may use each of the two kinds of representations, think about how you mentally represent all the facts you know about cats. Use your mental definition of the word *cat* and all the inferences you may draw from your mental image of a cat. Which kind of representation is more helpful for answering the following questions:

- Is a cat's tail long enough to reach the tip of the cat's nose if the cat is stretching to its full length?
- Do cats like to eat fish?
- Are the back legs and the front legs of a cat exactly the same size and shape?
- Are cats mammals?
- Which is wider—a cat's nose or a cat's eye?

Which kinds of mental representations were the most valuable for answering each of these questions?

Irina oxilixo Danilova/Shutterstock.com

We use visual images to solve problems and to answer questions involving objects (Joh, Jaswal, & Keen, 2011; Kosslyn, Thompson, & Ganis, 2006). Which is darker red—a cherry or an apple? How many windows are there in your house or apartment? How do you get from your home, apartment, or dormitory room to your first class of the day? How do you fit together the pieces of a puzzle or the component parts of an engine, a building, or a model? To solve problems and answer questions such as these, we visualize the objects in question, according to Kosslyn, Thompson, and Ganis (2006). In doing so, we mentally represent the images.

Many psychologists outside of cognitive psychology are interested in applications of mental imagery to other fields in psychology. Such applications include using guided-imagery techniques to control pain and to strengthen immune responses and otherwise promote health. With such techniques, you could imagine being at a beautiful beach and

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feeling comfortable, letting your pain fade into the background. Or you could imagine the cells of your immune system successfully destroying all the bad bacteria in your body. Such techniques are also helpful in overcoming psychological problems, such as phobias and other anxiety disorders. Design engineers, biochemists, physicists, and many other scientists and technologists use imagery to think about various structures and processes and to solve problems in their chosen fields.

Not everyone is equally skilled in creating and manipulating mental images, however. Research in applied settings and in the laboratory indicates that some of us are better able to create mental images than others (Borst & Kosslyn, 2010; Schienle, Schaefer, & Vaitl, 2008). These differences are even measurable with functional magnetic resonance imaging (fMRI; Cui et al., 2007). Research also indicates that the use of mental images can help to improve memory. In the case of people with Down syndrome, the use of mental images in conjunction with hearing a story improved memory for the material as compared with just hearing the story (de la Iglesia, Buceta, & Campos, 2005; Kihara & Yoshikawa, 2001). Mental imagery also is used in other fields such as occupational therapy. Using this technique, patients with brain damage train themselves to complete complex tasks. For instance, by imagining the details of the tasks in the correct order to remember all the details involved, patients with brain damage can wash dishes or take medication (Liu & Chan, 2009).

In what form do we represent images in our minds? According to an extreme view of imagery, all images of everything we ever sense may be stored as exact copies of physical images. But realistically, to store every observed physical image in the brain seems impossible. The capacity of the brain would be inadequate to handle such a task (Kosslyn & Pomerantz, 1977; Kosslyn, Thompson, & Ganis, 2006). Note the simple example in *Investigating Cognitive Psychology: Can Your Brain Store Images of Your Face?*

INVESTIGATING COGNITIVE PSYCHOLOGY

Can Your Brain Store Images of Your Face?

Look at your face in a mirror. Gradually turn your head from far right (to see yourself out of your left peripheral vision) to far left. Now tilt your head as far forward as you can and then tilt it as far back as you can. All the while, make sure you still are seeing your reflection. Now make a few different expressions, perhaps even talking to yourself to exaggerate your facial movements. Could your brain store this series of separate images of your face? Storing each of these images and every image you see every day for years likely is impossible for your brain. So how do we store images in our brains?

Amazingly, learning can indeed take place just by using mental images. A study by Tartaglia et al. (2009) presented participants with a vertical parallel arrangement of three lines (see Figure 7.4 ■). The middle one was closer either to the right or left outer line. Practice using mental images resulted in participants becoming more sensitive to the asymmetry toward either the left or right side. A study with architects also showed the importance of mental images. Whether or not they were permitted to draw sketches in the early design phase of a project did not affect the design outcome and cognitive activity—if they were not allowed to draw sketches, they just used mental imaging (Bilda, Gero, & Purcell, 2006).

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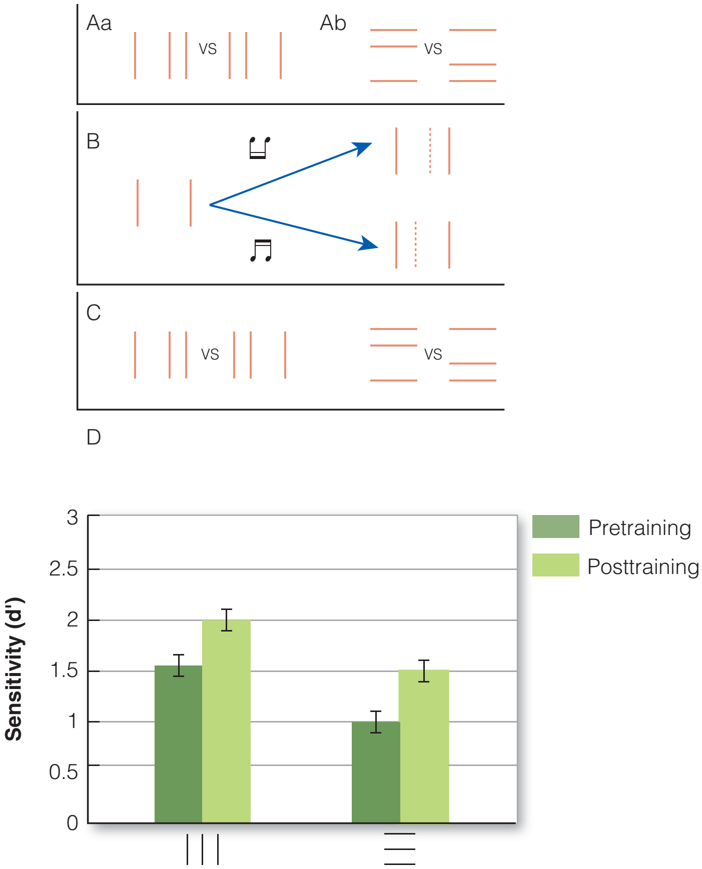

Figure 7.4 Learning Assisted by Mental Imagery. (Aa) and (Ab) show the kinds of stimuli participants were presented with. As you can see in (Aa), there are two outer vertical lines and a middle line that is offset to the right or the left. Participants had to judge whether the middle line was offset to the right or left. In (Ab), participants had to judge whether the horizontal middle line exhibited an upward or downward offset.

(B) illustrates the lines participants were shown in their subsequent imagery training. They saw just the two outer lines and then heard either a high-frequency or a low-frequency tone. When they heard they high-frequency tone, they were asked to imagine that the middle line is offset to the right; when they heard the low-frequency tone they were supposed to imagine the middle line as offset to the left. Note that participants did not train with horizontal lines, just with vertical ones.

(D) After the imagery training, participants were once again presented with horizontal and vertical lines as in (Aa) and (Ab), and their sensitivity to detecting an offset to the left and right had significantly increased. Remarkably, even though they had not done any mental imagery with the horizontal lines, learning transferred to the horizontal lines as well.

Dual-Code Theory: Images and Symbols

According to **dual-code theory**, we use both pictorial and verbal codes for representing information (Paivio, 1969, 1971) in our minds. These two codes organize information into knowledge that can be acted on, stored somehow, and later retrieved for subsequent use. According to Paivio, mental images are analog codes. **Analog codes** resemble the objects they are representing. For example, trees and rivers might be represented by analog codes. Just as the movements of the hands on an analog clock are analogous to the passage of time, the mental images we form in our minds are analogous to the physical stimuli we observe.

In contrast, our mental representations for words chiefly are represented in a symbolic code. A *symbolic code* is a form of knowledge representation that has been chosen arbitrarily to stand for something that does not perceptually resemble what is being represented. Just as a digital watch uses arbitrary symbols (typically, numerals) to represent the passage of time, our minds use arbitrary symbols (words and combinations of words) to represent many ideas. Sand can be used as well to represent the flow of time, as shown in the hourglass in Figure 7.5. A symbol may be anything that is arbitrarily designated to stand for something other than itself. For example, we recognize that the numeral "9" is a symbol for the concept of "nineness." It represents a quantity of nine of something. But nothing about the symbol in any way would suggest its meaning. We arbitrarily have designated this symbol to represent the concept. But "9" has meaning only because we use it to represent a deeper concept. Concepts like *justice* and *peace* are best represented symbolically.

Consistent with his dual-code theory, Paivio noted that verbal information seems to be processed differently than pictorial information. For example, in one study, participants

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Figure 7.5 Symbols Can Represent Ideas in Our Minds. This hourglass illustrates that we can depict the passage of time in various ways. We do not necessarily need numbers.

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Dual Coding

Look at the list of words that your friends and family members recalled in the demonstration in Chapter 6. Add up the total number of recollections for every other word (i.e., book, window, box, hat—the words in odd numbered positions in the list). Now add up the total number of recollections for the other words (i.e., peace, run, harmony, voice—the words in even numbered positions in the list). Most people will recall more words from the first set than from the second set. This is because the first set is made up of words that are concrete, or those words that are easily visualized. The second set of words is made up of words that are abstract or not easily visualized. This is a demonstration of the dual-code hypothesis (or its more contemporary version, the functional equivalence hypothesis).

were shown both a rapid sequence of pictures and a sequence of words (Paivio, 1969). They then were asked to recall the words or the pictures in one of two ways. One way was at random, so that they recalled as many items as possible, regardless of the order in which the items were presented. The other way was in the correct sequence.

Participants more easily recalled the pictures when they were allowed to do so in any order. But they more readily recalled the sequence in which the words were presented than the sequence for the pictures, which suggests the possibility of two different systems for recall of words versus pictures.

Other researchers have found supporting evidence for dual-code theory as well. For example, actual visual perception could interfere with simultaneous visual imagery, according to some hypotheses. Similarly, the need to produce a verbal response could interfere with the simultaneous mental manipulation of words. If, however, an experiment found that visual and verbal tasks do not interfere with each other, this result would indicate that the two kinds of tasks draw on two different systems.

A classic investigation tested this hypothesis (Brooks, 1968). Participants performed either a visual task or a verbal task. The visual task involved answering questions requiring judgments about a picture that was presented briefly. The verbal task involved answering questions requiring judgments about a sentence that was stated briefly. Participants expressed their responses verbally (saying "yes" or "no" aloud), visually (pointing to an answer), or manually (tapping with one hand to agree and the other to disagree). There were two conditions in which Brooks expected interference: a visual task requiring a visual (pointing) response and a verbal task requiring a verbal response. This prediction assumed that both task and response required the same system for completion. Interference was measured by slowdowns in response times. Brooks confirmed his hypothesis. Participants did show slower response times in performing the pictorial task when asked to respond using a competing visual display, as compared with when they were using a noninterfering response medium (i.e., either verbal or manual).

Similarly, his participants showed more interference in performing the verbal task when asked to respond using a competing verbal form of expression, as compared with how they performed when responding manually or by using a visual display. Thus, a response involving visual perception can interfere with a task involving manipulations of a visual image. Similarly, a response involving verbal expression can interfere with a task involving mental manipulations of a verbal statement. These findings suggest the use of two distinct codes for mental representation of knowledge. The two codes are an imaginal (analogical) code and a verbal (symbolic) code.

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in the lab of **DOUG MEDIN**

Our lab focuses on culture and cognition. Thinking back to when you first learned about psychological research, two key principles likely were (1) designing studies with appropriate comparison conditions to control for potential confounding factors and (2) randomly sampling participants so that the results can be generalized to the population at large. The latter principle is often discussed by showing how public opinion polls can be wrong if any sampling bias comes into play.

But sampling issues also are relevant to every research study done in cognitive psychology. These studies are overwhelmingly conducted with college students. This raises the possibility that the results observed might not necessarily generalize to humanity at large. This issue was highlighted by a recent review (Henrich et al., 2010) in which the authors argued that studies focused on Western, Educated, Industrialized, Rich, and Democratic (WEIRD) populations (i.e., college students) produced results that were distinctly "weird" and unrepresentative of the world in general. Their review covered the topics of perception, inductive reasoning and decision making, the meat and potatoes of cognitive psychology. These observations suggest that we cannot build a cognitive psychology by relying on college students alone for data.

Courtesy of Doug Medin

Doug Medin

In addition to testing the generalizability of findings, studies of culture allow us to select and examine sources of variation that we think might matter. Here's an example from our research team's work (led by cognitive anthropologist, Scott Atran) studying the categorization of and reasoning about biological kinds by Itza' Maya agro-foresters living in the lowland rainforest of Guatemala. We found that Itza' Maya adults reasoned very differently from U.S. college students and did not show effects predicted by the then-current theories of inductive reasoning (which were based on college students). We knew we were on to something, but we worried about whether the reasoning task was too artificial for Maya adults, whether they had understood the instructions, and a host of other issues.

We had also observed that Northwestern University college students know little about the tall woody plants scattered throughout our campus and preferred to simply name them as "trees." This led us to consider the possibility that the source of cultural differences in reasoning about biological kinds might be knowledge. Compared with college students, Itza' Maya are hands-down biological experts and they depend on the forest for foods and medicines.

This led us to study biological categorization and reasoning among U.S. experts (e.g., parks maintenance personnel, avid bird watchers, experienced fishermen). These experts reasoned like the Itza' Maya and not like college students. Here's a concrete example. Suppose that we know that White Pine and Weeping Willow get Disease X and Paper Birch and River Birch get Disease Y. Which disease is more likely to affect all trees? Even if you don't know these trees, you are likely to say X because pines and willows are more different than two kinds of birch. But U.S. tree experts are likely to say Y on grounds that birches grow everywhere and are very susceptible to disease, so there would be good chances for the disease to spread. These findings led us to new theories of inductive reasoning.

This work contributes to the field of cognitive psychology, but it also is relevant to the practical issue of whether humans can live on the earth without destroying it. Other studies by our team with the Itza' Maya suggest that, unlike other groups living in the same area, Itza' agro-forestry practices are sustainable (Atran & Medin, 2008). These and other studies (e.g., ongoing studies of environmental perception and practices among indigenous Ngöbe in Panama) suggest that we WEIRD people have a lot to learn.

Storing Knowledge as Abstract Concepts: Propositional Theory

Not everyone subscribes to the dual-code theory. Researchers have developed an alternative theory termed a conceptual-propositional theory, or propositional theory (Anderson & Bower, 1973; Pylyshyn, 1973, 1984, 2006). **Propositional theory**

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suggests that we do not store mental representations in the form of images or mere words. We may experience our mental representations as images, but these images are *epiphenomena*—secondary and derivative phenomena that occur as a result of other more basic cognitive processes. According to propositional theory, our mental representations (sometimes called "mentalese") more closely resemble the abstract form of a proposition. A proposition is the meaning underlying a particular relationship among concepts. Anderson and Bower (1973) have moved beyond their original conceptualization of propositional theory to a more complex model that encompasses multiple forms of mental representation. Others, such as Pylyshyn (2006), however, still hold to their original position.

What Is a Proposition?

How would a propositional representation work? Consider an example. To describe Figure 7.3(a), you could say, "The table is above the cat." You also could say, "The cat is beneath the table." Both of these statements indicate the same relationship as "above the cat is the table." With a little extra work, you probably could come up with a dozen or more ways of verbally representing this relationship.

Logicians have devised a shorthand means, called *predicate calculus*, to express the underlying meaning of a relationship. This method attempts to strip away the various superficial differences in the ways we describe the deeper meaning of a proposition:

[Relationship between elements]([Subject element], [Object element])

The logical expression for the proposition underlying the relationship between the cat and the table is shown in Figure 7.3(c). This logical expression, of course, would need to be translated by the brain into a format suitable for its internal mental representation.

Using Propositions

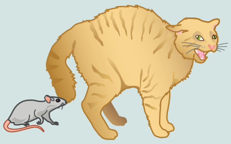
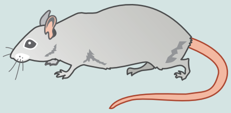
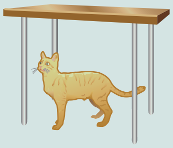
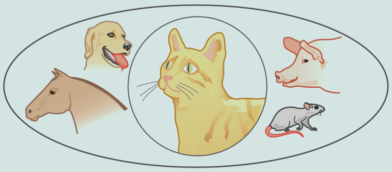
It is easy to see why the hypothetical construct of propositions is so widely accepted among cognitive psychologists. Propositions may be used to describe any kind of relationship. Examples of relationships include actions of one thing on another, attributes of a thing, positions of a thing, class membership of a thing, and so on, as shown in Table 7.1 ■. In addition, any number of propositions may be combined to represent more complex relationships, images, or series of words. An example would be "The furry mouse bit the cat, which is now hiding under the table." The key idea is that the propositional form of mental representation is neither in words nor in images. Rather, it is in an abstract form representing the underlying meanings of knowledge. Thus, a proposition for a sentence would not retain the acoustic or visual properties of the words. Similarly, a proposition for a picture would not retain the exact perceptual form of the picture (Clark & Chase, 1972).

According to the propositional view (Clark & Chase, 1972), both images [e.g., of the cat and the table in Figure 7.3(a)] and verbal statements [e.g., in Figure 7.3(b)] are mentally represented in terms of their deep meanings, and not as specific images or words. That is, both pictorial and verbal information is encoded and stored as propositions. Then, when we wish to retrieve the information from storage, the propositional representation is retrieved. From it, our minds recreate the verbal or the imaginal code relatively accurately.

Some evidence suggests that these representations need not be exclusive. People seem to be able to employ both types of representations to increase their performance on cognitive tests (Talasli, 1990).

Table 7.1 Propositional Representations of Underlying Meanings

We may use propositions to represent any kind of relationship, including actions, attributes, spatial positions, class membership, or almost any other conceivable relationship. The possibility for combining propositions into complex propositional representational relationships makes the use of such representations highly flexible and widely applicable.

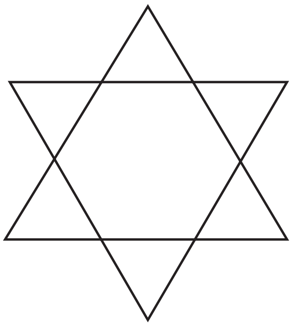
Type of Relationship	Representation in Words	Propositional Representation[1]	Imaginal Representation
Actions	A mouse bit a cat.	Bite [action] (mouse [agent of action], cat [object])	
Attributes	Mice are furry.	[external surface characteristic] (furry [attribute], mouse [object])	
Spatial positions	A cat is under the table.	[vertically higher position] (table, cat)	
Class or Category membership	A cat is an animal.	[categorical membership] (animal [category], cat [member])	

*In this table, propositions are expressed in a shorthand form (known as *predicate calculus*) commonly used to express underlying meaning. This shorthand is intended only to give some idea of how the underlying meaning of knowledge might be represented. It is not believed that this form is literally the form in which meaning is represented in the mind. In general, the shorthand form for representing propositions is this: [Relationship between elements] ([subject element], [object element]).

Do Propositional Theory and Imagery Hold Up to Their Promises?

The controversy over whether we represent information in our memory by means of propositions or mental images continues in the 21st century (e.g., see Kosslyn, Thompson, & Ganis, 2006; Pylyshyn, 2006). Both theories have their limits. We explore these limits in the next section.

Limitations of Mental Images



■ **Figure 7.6 Mental Images.** Quickly glance at this figure and then cover it with your hand. Imagine the figure you just saw. Does it contain a parallelogram?

Source: Based on *Cognition,* Third Edition, by Margaret W. Matlin. Copyright © 1994 by Holt, Rinehart and Winston.

What are the limits to analogical representation of images? For example, look quickly at Figure 7.6 ■, and then look away. Does Figure 7.6 contain a *parallelogram* (a four-sided figure that has two pairs of parallel lines of equal length)? Participants in one study looked at figures such as this one. They had to determine whether particular shapes (e.g., a parallelogram) were or were not part of a given whole figure (Reed, 1974). Overall performance was little better than chance. The participants appeared unable to call up a precise analogical mental image. They could not use a mental image to trace the lines to determine which component shapes were or were not part of a whole figure. To Reed,

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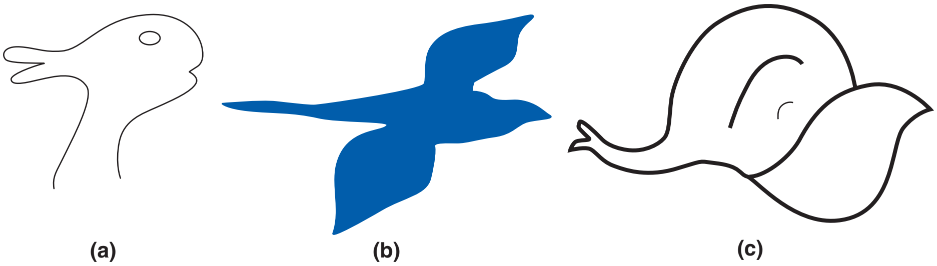

■ **Figure 7.7** **Can Mental Images Be Ambiguous?** (a) Look closely at the rabbit, then cover it with your hand and recreate it in your mind. Can you see a different animal in this image just by mentally shifting your perspective? (b) What animal do you observe in this figure? Create a mental image of this figure, and try to imagine the front end of this animal as the back end of another animal and the tail end of this animal as the front end of another animal. (c) Observe the animal in this figure, and create a mental image of the animal; cover the figure, and try to reinterpret your mental image as a different kind of animal (both animals probably are facing in the same direction).

Sources: Based on D. Chambers and D. Reisberg (1985), "Can Mental Images be Ambiguous?" *Journal of Experimental Psychology: Human Perception and Performance,* 11, 317–328. Copyright © 1985 by the American Psychological Association.

these findings suggested the use of a propositional code rather than an analogical one. Examples of a propositional code would be "a Star of David" or "two overlapping triangles, one of which is inverted." Another possible explanation is that people have analogical mental images that are imprecise in some ways.

There are additional limits to knowledge representation in mental images (Chambers & Reisberg, 1985, 1992).

- Look at Figure 7.7(a) ■.
- Now cover the image and imagine the rabbit shown in the figure.

Actually, the figure shown here is an *ambiguous figure,* meaning that it can be interpreted in more than one way. Ambiguous figures often are used in studies of perception. But researchers decided to use such figures to determine whether mental representations of images are truly analogical to perceptions of physical objects (i.e., if mental images are indeed representations similar to what our eyes see).

- Without looking back at the figure, can you determine the alternative interpretation of Figure 7.7(a)?

When the participants in Chambers and Reisberg's study (1992) had difficulty, the researchers offered cues. But even participants with high visualization skills often were unable to conjure the alternative interpretation. Finally, the investigators suggested to participants that they should draw the figures out of their memory.

- Without looking again at the figure, briefly sketch Figure 7.7(a), based on your mental representation of it.
- Once you have completed your sketch, try once more to see whether you can find an alternative interpretation of the figure.

If you are like most of Chambers and Reisberg's (1992) participants, you need to have an actual *percept* (object of perception) of the figure in front of you so you can guess at an alternative interpretation of the figure. These results indicate that mental representations of figures are not the same as percepts of these figures. In case you have not yet guessed it, the alternative interpretation of the rabbit is a duck. In this interpretation, the

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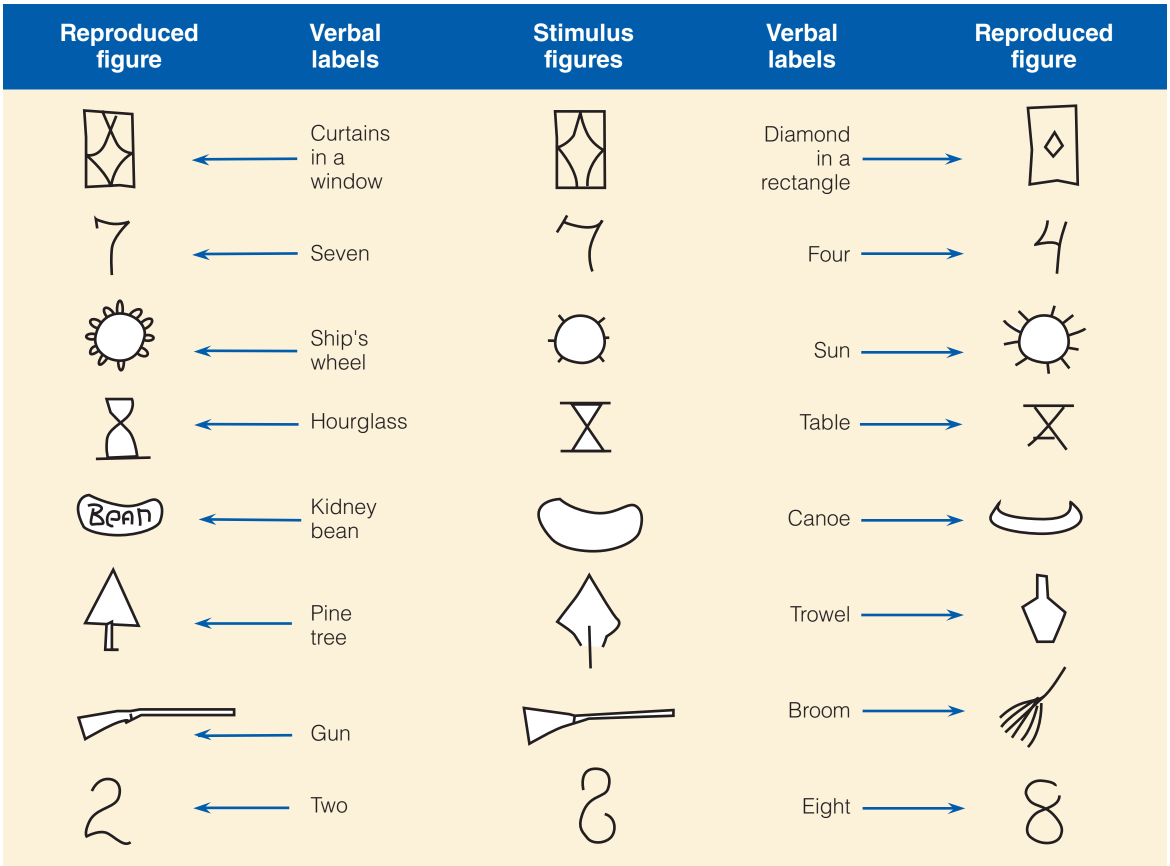
rabbit's ears are the duck's bill. One interpretation of Chambers and Reisberg's findings—an implausible one—is that people plainly do not use images to represent what they see. An alternative and more plausible explanation is that a propositional code may override the imaginal code in some circumstances.

Early studies have suggested that visual images can be distorted through verbal information. Participants were asked to view figures that were labeled. When they recalled the images, they were distorted in the direction of the meaning of the images. For example, participants remembered an abstract figure labeled "hourglass" to look more like a typical hourglass than it actually did.

Much earlier work suggested that semantic (verbal) information (e.g., labels for figures) tends to distort recall of visual images in the direction of the meaning of the images (Carmichael, Hogan, & Walter, 1932). For example, for each of the figures in the center column of Figure 7.8 ■, observe the alternative interpretations for the figures recalled. Recall differs based on the differing labels given for the figures.

Limitations of Propositional Theory

In contrast to the work just discussed, some evidence indicates that we do not necessarily need a propositional code to manipulate information, but we can manipulate mental imagery directly.


Reproduced figure
Verbal labels
Stimulus figures
Verbal labels
Reproduced figure
Curtains in a window
Diamond in a rectangle
Seven
Four
Ship's wheel
Sun
Hourglass
Table
Bean
Kidney bean
Canoe
Pine tree
Trowel
Gun
Broom
Two
Eight

■ **Figure 7.8** **The Influence of Semantic Labels.** Semantic labels clearly influence mental images, as shown here in the differing drawings based on mental images of objects given differing semantic (verbal) labels.

Source: Based on After Carmichael, Hogan, & Walter, 1932 [Carmichael, L., Hogan, H. P., & Walter, A. A. (1932). An experimental study of the effect of language on the reproduction of visually perceived form. *Journal of Experimental Psychology,* 15, 73–86.]

Participants in a study by Finke, Pinker, and Farah (1989) manipulated mental images by combining two distinct images to form a different mental image altogether. This manipulation of mental images may be thought of as an imaginal Gestalt experience. In the combined image, the whole of the two combined images differed from the sum of its two distinct parts. The study showed that in some situations, mental images can be combined effectively (e.g., the letter *H* and the letter *X*) to create mental images. The images may be of geometric shapes (e.g., right triangles), of letters (e.g., *M*), or of objects (e.g., a bow tie).

It appears that propositional codes are less likely to influence imaginal ones when participants create their own mental images, rather than when participants are presented with a picture to be represented. Propositional codes, however, may influence imaginal ones. This influence is especially likely to occur when the picture used to create an image is ambiguous [as in Figure 7.7(a)–(c) ■] or rather abstract (as in Figure 7.6).

Other investigators have built on Finke's work regarding the construction of mental images (Finke, Pinker, & Farah, 1989). They presented an alternative view of Chambers and Reisberg's findings regarding the manipulation of ambiguous figures (Peterson et al., 1992). They believe that the mental reinterpretation of ambiguous figures involves two manipulations:

1. The first is a mental *realignment* of the reference frame. This realignment would involve a shift in the positional orientations of the figures on the mental "page" or "screen" on which the image is displayed. In Figure 7.7(a), the shift would be of the duck's back to the rabbit's front, and the duck's front to the rabbit's back.
2. The second manipulation is a mental *reconstrual* (reinterpretation) of parts of the figure. This reconstrual would be of the duck's bill as the rabbit's ears.

Participants may be unlikely to manipulate mental images spontaneously to reinterpret ambiguous figures, but such manipulations occur when participants are given the right context.

Under what conditions do participants mentally reinterpret their image of the duck rabbit figure [see Figure 7.7(a)] and of some other ambiguous figures (Peterson et al., 1992)? What are the supporting hints? Across experiments, 20% to 83% of participants were able to reinterpret ambiguous figures, using one or more of the following hints:

1. *Implicit reference frame hint*. Participants first were shown another ambiguous figure involving realignment of the reference frame [e.g., see Figure 7.7(b) ■]; a hawk's head/a goose's tail, and a hawk's tail/a goose's head).
2. *Explicit reference frame hint*. Participants were asked to modify the reference frame by considering either "the back of the head of the animal they had already seen as the front of the head of some other animal" (Peterson et al., 1992, p. 111; considered a conceptual hint) or "the front of the thing you were seeing as the back of something else" (p. 115; considered an abstract hint).
3. *Attentional hint*. Participants were directed to attend to regions of the figure where realignments or reconstruals were to occur.
4. *Construals from "good" parts*. Participants were asked to construe an image from parts determined to be "good" (according to both objective [geometrical] and empirical [interrater agreement] criteria), rather than from parts determined to be "bad" (according to similar criteria).

Additionally, some spontaneous reinterpretation of mental images for ambiguous figures may occur. This is particularly likely for images of figures that may be reinterpreted without realigning the reference frame. For example, see Figure 7.7(c), which may be a whole snail or an elephant's head, or possibly even a bird, a helmet, a leaf, or a seashell.

The investigators went on to suggest that the processes involved in constructing and manipulating mental images are similar to the processes involved in perceptual processes (Peterson et al., 1992). An example would be the recognition of forms (discussed in Chapter 3). Not everyone agrees with this view. Some support for these views has been found by cognitive psychologists who hold that mental imagery and visual perception are functionally equivalent. Here, *functional equivalence* refers to individuals using about the same operations to serve about the same purposes for their respective domains.

Overall, the weight of the evidence seems to indicate there are multiple codes rather than just a single code. But the controversy continues (Kosslyn, Thompson, & Ganis, 2006; Pylyshyn, 2006).

CONCEPT CHECK

1. In what forms can knowledge be represented in our mind?
2. What kinds of codes does dual-code theory comprise?
3. What is a proposition?

Mental Manipulations of Images

According to the **functional equivalence hypothesis**, although visual imagery is not identical to visual perception, it is functionally equivalent to it. Functionally equivalent things are strongly analogous to each other—they can accomplish the same goals. The functionally equivalent images are thus analogous to the physical percepts they represent. This view essentially suggests that we use images rather than propositions in knowledge representation for concrete objects that can be pictured in the mind. This view has many advocates (e.g., Farah, 1988b; Finke, 1989; Jolicoeur & Kosslyn, 1985a, 1985b; Rumelhart & Norman, 1988; Shepard & Metzler, 1971).

Principles of Visual Imagery

One investigator has suggested some principles of how visual imagery may be functionally equivalent to visual perception (Finke, 1989). These principles may be used as a guide for designing and evaluating research on imagery. Table 7.2 ■ offers an idea of some of the research questions that may be generated, based on Finke's principles.

Neuroscience and Functional Equivalence

Evidence for functional equivalence can be found in neuroimaging studies. In one study, for example, participants either viewed or imagined an image. Activation of similar brain areas was noted, in particular, in the frontal and parietal regions (Ganis, Thompson, & Kosslyn, 2004). Additionally, imagery can evoke responses in high-level visual brain areas and the visual primary cortex—areas that are highly involved in the processing of visual stimuli we see with our eyes (Ishii et al., 2000; Reddy et al., 2010; Thirion et al., 2006).

In a recent study, participants were first familiarized with the images of several objects and how to visualize them vividly (Lee, Kravitz, & Baker, 2012). Then the participants were either presented with the objects or were asked to visualize them. The researchers found that while both imagery and perception used similar brain areas, the

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Table 7.2 Principles of Visual Imagery: Questions

According to the functional equivalence hypothesis, we represent and use visual imagery in a way that is functionally equivalent (strongly analogous) to that for physical percepts. Ronald Finke has suggested several principles of visual imagery that may be used to guide research and theory development.

Principle	Possible Questions Generated from Principles
1. Our mental transformations of images and our mental movements across images correspond to those of physical objects and percepts.	Do our mental images follow the same laws of motion and space that are observed in physical percepts? For example, does it take longer to manipulate a mental image at a greater angle of rotation than at a smaller one? Does it take longer to scan across a large distance in a mental image than across a smaller distance?
2. The spatial relations among elements of a visual image are analogous to those relations in actual physical space.	Are the characteristics of mental images analogous to the characteristics of percepts? For example, is it easier to see the details of larger mental images than of smaller ones? Are objects that are closer together in physical space also closer together in mental images of space?
3. Mental images can be used to generate information that was not explicitly stored during encoding.	After participants have been asked to form a mental image, can they answer questions that require them to infer information based on the image that was not specifically encoded at the time they created the image? For example, suppose that participants are asked to picture a tennis shoe. Can they later answer questions such as "How many laceholes are there in the tennis shoe?"
4. The construction of mental images is analogous to the construction of visually perceptible figures.	Does it take more time mentally to construct a more complex mental image than a simpler one? Does it take longer to construct a mental image of a larger image than of a smaller one?
5. Visual imagery is functionally equivalent to visual perception in terms of the processes of the visual system used for each.	Are the same regions of the brain involved in manipulating mental imagery as are involved in manipulating visual percepts? For example, are similar areas of the brain activated when mentally manipulating an image, as compared with those involved when physically manipulating an object?

contributions of the areas and their levels of activation differed depending on whether the participants actually saw or just mentally imagined an object. This finding makes sense given that there is no visual input from the eyes during imagery, which leads to a decrease in information compared with visual perception. This decrease in information has two consequences: Internal processing is less complex because there is less information to deal with, and signals are probably also less differentiated between different brain regions.

Schizophrenia provides an interesting example of the similarities between perception and imagery. Many people who suffer from schizophrenia experience auditory hallucinations. Auditory hallucinations are experiences of "hearing" that occur in the absence of actual auditory stimuli. This "hearing" is the result of internally generated material. These patients have difficulty discriminating between many different types of self-produced and externally provided stimuli (Blakemore et al., 2000). Evidence from other researchers reveals that during auditory hallucinations the auditory cortex is activated abnormally (Lennox et al., 2000). Additionally, activation of brain areas involved with receptive language (i.e., hearing or reading as opposed to speaking or writing) is observed during auditory hallucinations (Ishii et al., 2000). In sum, it is believed that

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auditory hallucinations occur at least in part because of malfunctions of the auditory imaging system and problematic perception processes (Seal, Aleman, & McGuire, 2004). These challenges make it difficult for afflicted individuals to differentiate between internal images and the perception of external stimuli.

These results suggest that there is indeed functional equivalence between what our senses perceive and what we create in our minds. In the following section, we will explore the mental manipulation of images in more detail.

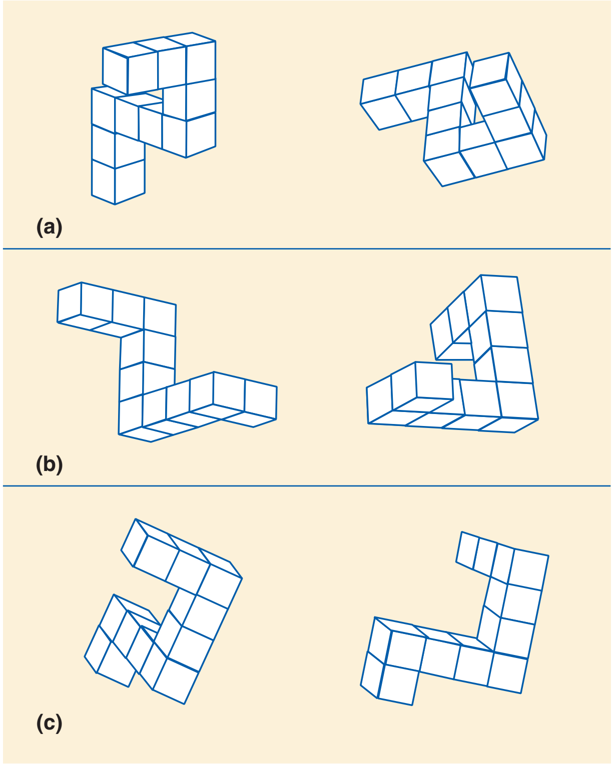
Mental Rotations

Mental images can be manipulated in many ways. They can be rotated just like physical objects. We can zoom into mental images to see more details of a specific area, or we can scan across an image from one point to another. Keep in mind that studies about mental image manipulations also give us some indication of whether the functional equivalence hypothesis is indeed correct—that is, of whether mental images and the images we see with our eyes work in the same way and adhere to the same principles.

How Does Mental Rotation Work?

Mental rotation involves rotationally transforming an object's visual mental image (Takano & Okubo, 2003; Zacks, 2008). Just like you can physically rotate a water bottle you hold in your hands, you can also imagine a water bottle in your mind and rotate it in the mind.

In a classic experiment, participants were asked to observe pairs of pictures showing 3-D geometric forms (Shepard & Metzler, 1971). The forms were rotated from 0 to 180 degrees (Figure 7.9 ■). The rotation was either in the picture plane [i.e., in



■ **Figure 7.9** **Mental Rotations.** For which of these pairs of figures does the figure on the right show an accurate rotation of the figure on the left?

Source: Based on "Mental Rotation," by R. Shepard and J. Metzler. *Science*, 171(3972), 701–703. Copyright ©1971, American Association for the Advancement of Science.

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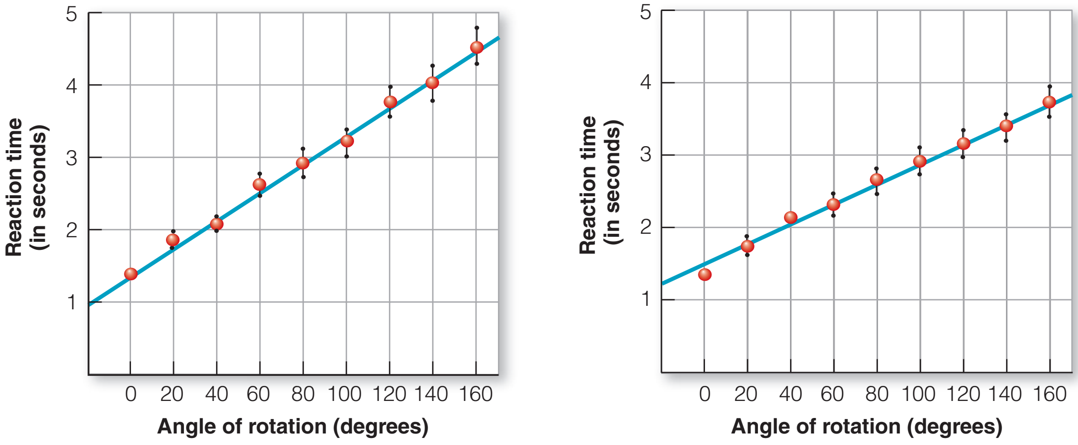

(a) Picture-plane pairs **(b) Depth pairs**

■ **Figure 7.10 Response Times for Mental Rotation.** Response times to questions about mental rotations of figures show a linear relationship to the angle of rotation, and this relationship is preserved, whether the rotations are in the picture plane or are in depth.

Source: Based on "Mental Rotation," by R. Shepard and J. Metzler. *Science*, 171(3972), 701–703. Copyright © 1971, American Association for the Advancement of Science.

two-dimensional (2-D) space clockwise or counterclockwise; Figure 7.9(a)] or in depth [i.e., in 3-D space; Figure 7.9(b)].

In addition, participants were shown distracter forms. These forms were not rotations of the original stimuli [Figure 7.9(c)]. Participants then were asked to tell whether a given image was or was not a rotation of the original stimulus.

The response times for answering the questions about the rotation of the figures formed a *linear function* of the degree to which the figures were rotated (Figure 7.10 ■). For each increase in the degree of rotation of the figures, there was a corresponding increase in the response times. Furthermore, there was no significant difference between rotations in the picture plane and rotations in depth. These findings are functionally equivalent to what we might expect if the participants had been rotating physical objects in space. To rotate objects at larger angles of rotation takes longer. Whether the objects are rotated clockwise, counterclockwise, or in the third dimension of depth makes little difference. The finding of a relation between degree of angular rotation and reaction time has been replicated a number of times with a variety of stimuli (e.g., Gogos et al., 2010; Van Selst & Jolicoeur, 1994; see also Tarr, 1999).

To try your own hand at mental rotations, do the demonstration in the *Investigating Cognitive Psychology: Try Your Skills at Mental Rotations* box for yourself (based on Hinton, 1979). ■ See also Lab 38, Mental Rotation, in CogLab.

Other researchers have supported these original findings in other studies of mental rotations. For example, they have found similar results in rotations of 2-D figures, such as letters of the alphabet (Gogos et al., 2010; Jordan & Huntsman, 1990), cubes (Just & Carpenter, 1985; Peters & Battista, 2008), and body parts, in particular hands (Fiorio, Tinazzi, & Aglioti, 2006; Fiorio et al., 2007; Takeda et al., 2009). In addition, response times are longer for *degraded stimuli*—stimuli that are blurry, incomplete, or otherwise less informative (Duncan & Bourg, 1983)—than for intact stimuli. Response times are also longer for complex items compared with simple items (Bethell-Fox & Shepard, 1988) and for unfamiliar figures compared with familiar ones (Jolicoeur, Snow, & Murray, 1987). Older adults have more difficulty with this task than do younger adults (Band & Kok, 2000).

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INVESTIGATING
COGNITIVE PSYCHOLOGY

Try Your Skills at Mental Rotation

Imagine a cube floating in the space in front of you. Now, mentally grasp the left front bottom corner of the cube with your left hand. Also grasp the right back top corner of the cube with your right hand. While mentally holding those corners, rotate the cube so that the corner in your left hand is directly below the corner in your right hand (as if to form a vertical axis around which the cube would spin). How many corners of the imaginary cube are in the middle (i.e., not being grasped by your hands)? Describe the positions of the corners.

How well did you do with this mental rotation? Few people have experience with mental rotation of geometric shapes. Most people imagine that there are four remaining corners of the cube being held by the two corners in their hands. They further imagine that all four corners are aligned on a horizontal plane, parallel to the ground. In fact, six corners remain. Only two corners are aligned in a given horizontal plane (parallel to the ground) at any one time.

The benefits of increased familiarity also may lead to *practice effects*—improvements in performance associated with increased practice. When participants have practice in mentally rotating particular figures (increasing their familiarity), their performance improves (Bethell-Fox & Shepard, 1988). This improvement, however, appears not to carry over to rotation tasks for novel figures (Jolicoeur, 1985; Wiedenbauer, Schmid, & Jansen-Osmann, 2007).

Moreover, children and young adults showed speedier response times in mental rotation tasks when given opportunities for practice (Kail & Park, 1990). The performance of both school-aged children and young adults on mental rotation tasks is not impaired as a function of their engaging in simultaneous tasks involving memory recall (Kail, 1991). These findings suggest that mental rotation may be an automatic process for school-aged children and adults. Given that familiarity with the items and practice with mental rotation appear to enhance response times, Robert Kail's work suggests that mental rotation may be an automatic process. Thus, enhanced response times may be the result of increasing automatization of the task across the years of childhood and adolescence. Furthermore, such automatic processes may be a sign of more effective visuospatial skills because increased speed is associated with increased accuracy in spatial memory (Kail, 1997).

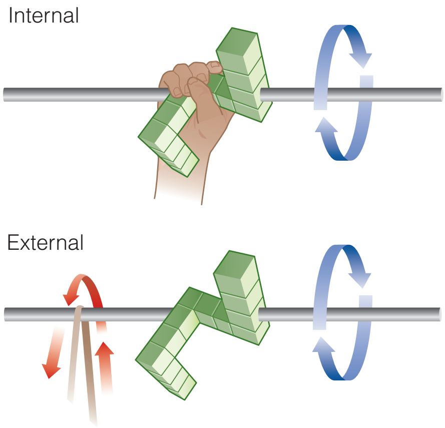
At the other end of the life span, two investigators studied whether processing speed or other factors may influence age-related changes in mental rotation by adults (Dror & Kosslyn, 1994). They found that older participants (55 to 71 years; mean 65 years) responded more slowly and less accurately than did younger participants (18 to 23 years; mean 20 years) on mental rotation tasks, a finding that has been replicated (Band & Kok, 2000; Inagaki et al., 2002). They also found, however, that older and younger participants showed comparable response times and error rates on tasks involving image scanning. On the basis of these and other findings, the authors concluded that aging affects some aspects of visual imagery more than others.

Neuroscience and Mental Rotation

Is there any physiological evidence for mental rotation? One type of study involves the brains of primates, animals whose cerebral processes seem most closely analogous to our own. Using single-cell recordings in the motor cortex of monkeys, investigators found some physiological evidence that monkeys can do mental rotations (Georgopoulos et al., 1989). Each monkey had been trained physically to move a handle in a specific direction toward a target light used as a reference point. Wherever the target light appeared, the monkeys were to use that point as a reference for the physical rotation of the handle. During these physical rotations, the monkey's cortical activity was recorded. Later, in the absence of the handle, the target light again was presented at various locations. The cortical activity again was recorded. During these presentations, activity in the motor cortex showed an interesting pattern. The same individual cortical cells tended to respond as if the monkeys were anticipating the particular rotations associated with particular locations of the target light. Another study examining mental rotation also indicates that the motor cortex (areas in the posterior frontal cortex) is activated during this task. The areas associated with hand movement were particularly active during the mental rotation task (Eisenegger, Herwig, & Jäncke, 2007; Zacks, 2008).

Preliminary findings based on primate research suggest that areas of the cerebral cortex have representations that resemble the 2-D spatial arrangements of visual receptors in the retina of the eye. These mappings may be construed as relatively depictive of the visual arrays in the real world (Cohen et al., 1996; Kosslyn et al., 1995). Perhaps if these same regions of the cortex are active in humans during tasks involving mental imagery, mental imagery may be similarly illustrative of the real world in mental representation.

Current brain-imaging techniques have allowed researchers to create images of human brain activity noninvasively to address such speculations. For example, in a study using fMRI, investigators found that the same brain areas involved in perception also are involved in mental rotation tasks. In one study, participants physically rotated objects instead of merely watching them being rotated. Later, they imagined the rotation of these objects. Parts of their motor cortex were activated that normally would not have been activated during mental rotation. In other words, the prior physical rotation of the objects affected the way their brains later processed the mental rotations of images of those objects (see Figure 7.11 ■; Kosslyn, Ganis, & Thompson, 2001). Of particular importance is the early visual cortex. It is the first area that receives input from the retina when we see an object. The early visual cortex (in particular, areas 17 and 18) is activated during imagery. Furthermore, when area 17 is impaired by means of transcranial magnetic stimulation (TMS), imagery is compromised as well (Kosslyn et al., 1999). In mental rotation, the primary motor cortex is activated when participants imagine manually rotating a stimulus (but not when they imagine a rotation driven by an electric motor; Kosslyn et al., 2001). Thus, not only are imagery and perception functionally equivalent in many psychological studies, neuropsychological techniques also verify this equivalence by demonstrating overlapping brain activity.



■ **Figure 7.11 Mental Rotation of an Object.** This illustration shows the way participants in the experiment of Kosslyn, Ganis, and Thompson (2001) either rotated an object themselves ("internal action") or saw the object being rotated by an electric motor ("external action").

Does mental imagery also involve the same mechanisms as memory processes because we have to recall those images from memory? If so, the functional equivalence hypothesis for perception would lose some ground. If imagery is "functionally equivalent" to everything, then, in effect, it really is equivalent to nothing.

A careful review cites many psychological studies that find differences between human imagery and memory tasks so we can assume that these two kinds of tasks are not functionally equivalent (Georgopoulos & Pellizzer, 1995).

In sum, evidence is converging, both from traditional and neuropsychological studies, to lend support to the hypothesis of functional equivalence between perception and mental imagery. Further neuropsychological work on images and propositions will be discussed later in the chapter.

Gender and Mental Rotation

Mental rotation has been extensively studied in addition to its application to the theories of imagery. A number of studies have highlighted an advantage for males over females in mental rotation tasks (Maeda & Yoon, 2013; Roberts & Bell, 2000a, 2000b, 2003), but others have not (Beste, Heil, & Konrad, 2010; Jäncke & Jordan, 2007; Jansen-Osmann & Heil, 2007). A number of studies that have not found gender differences have used characters (like letters or numbers) for mental rotation; therefore, it is possible that the rotation of characters engages different processes than the mental rotation of other objects. Some researchers have speculated that this advantage has decreased since it was first observed. A number of other interesting features of this effect have been identified.

First, in young children, no gender difference exists either in performance or in neurological activation (Roberts & Bell, 2000a, 2000b). Second, there seem to be differences in the activation of the parietal regions between men and women. There is less parietal activation for women than for men completing the same mental rotation task. Women, however, exhibit additional inferior frontal activation (Hugdahl, Thomsen, & Ersland, 2006; Thomsen et al., 2000; Zack, 2008). Thus, in women, spatial tasks involve both sides of the brain, whereas in men, the right side dominates this function. The differences in brain activation may mean that men and women use different strategies to solve mental rotation problems (Blake, McKenzie, & Hamm, 2002; Hugdahl, Thomsen, & Ersland, 2006; Jordan et al., 2002). Additionally, women have a proportionally greater amount of gray matter in the parietal lobe than do men, which is associated with a performance disadvantage for mental rotation tasks for the women (as they need increased effort to complete the tasks; Koscik et al., 2009). Training causes the gender difference to decrease or even to disappear (Bosco, Longoni, & Vecchi, 2004; Kass, Ahlers, & Dugger, 1998). A recent meta-analysis integrating 40 studies found that gender differences (favoring men) became larger when stricter time limits were set to solve the items. Although it is not clear why this was the case, it may be that test anxiety increases more in women than in men when stricter time limits apply or simply that cognitive processing for problem solving is faster in males (Maeda & Yoon, 2013; see also Lu & Sireci, 2007).

Zooming in on Mental Images: Image Scaling

The key idea underlying research on image size and scaling is that we represent and use mental images in ways that are functionally equivalent to our representations and uses of percepts. In other words, we use mental images the same way we use our actual perceptions.

For example, when you look at a building from afar, you won't be able to see as many details as when you are close by, and you may not be able to see things as clearly. Our *resolution* is limited. In general, seeing details of large objects is easier than seeing such details of small ones. We respond more quickly to questions about large objects we observe than to questions about small ones we observe. Now, if we assume that perception and mental representations are functionally equivalent, then participants should respond more quickly to questions about features of large imagined objects than to questions about features of small ones.

What happens when we zoom in closer to objects to perceive details? Sooner or later, we reach a point at which we can no longer see the entire object. To see the whole object once more, we must zoom out. See *Investigating Cognitive Psychology: Imaging Scaling* to observe perceptual zooming for yourself.

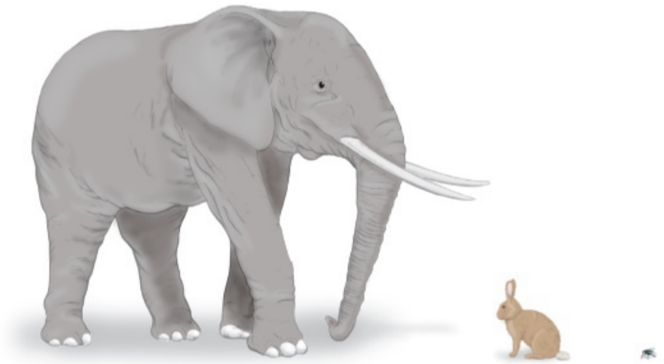
In research on visual perception, it is easy for researchers to control the sizes of the objects you see. For research on image size, however, controlling the sizes of people's mental images is more difficult. How do you know that the image of the elephant in your head is the same size as the image of the elephant in someone else's head? Fortunately, there are some ways to get around this problem (Kosslyn, 1975).

INVESTIGATING COGNITIVE PSYCHOLOGY

Image Scaling

Find a large bookcase (floor to ceiling, if possible; if not, observe the contents of a large refrigerator with an open door). Stand as close to the bookcase as you can while still keeping all of it in view. Now, read the smallest writing on the smallest book in the bookcase. Without changing your gaze, can you still see all of the bookcase? Can you read the title of the book farthest from the book on which you are focusing your perception? Depending on what you want to see (a detail like a book title or the whole shelf), you may have to zoom in and out of what you see. When you look at a small detail, it will be hard to perceive the whole shelf, and vice versa. The same is true for mental images.

One of the ways is to use relative size as a means of manipulating image size (Kosslyn, 1975). Participants imagine four pairs of animals—an elephant and a rabbit, a rabbit and a fly, a rabbit and an elephant-sized fly, and a rabbit and a fly-sized elephant (see Figure 7.12 ■ and *Investigating Cognitive Psychology: Image Scanning*). Then the participants answer specific questions about the features of the rabbit and are timed in their responses. It takes them longer to describe the details of smaller objects than to describe the details of the larger objects. That is, it takes longer to respond to rabbits paired with elephants or with elephant-sized flies than to respond to rabbits



■ **Figure 7.12 Zooming in on Details.** Stephen Kosslyn (1983) asked participants to imagine either a rabbit and a fly (to observe zooming in to "see" details) or a rabbit and an elephant (to observe whether zooming in may lead to apparent overflow of the image space).

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paired with flies or with fly-sized elephants. This result makes sense intuitively: Imagine we each have a mental screen for visual images and look at an elephant's eye. The larger the eye on the screen, the more details we can see (Kosslyn, 1983; Kosslyn & Koenig, 1992).

INVESTIGATING COGNITIVE PSYCHOLOGY

Image Scanning

Look at the rabbit and the fly in Figure 7.12. Close your eyes and picture them both in your mind. Now, in your imagination, look only at the fly and determine the exact shape of the fly's head. Do you notice yourself having to take time to zoom in to "see" the detailed features of the fly? If you are like most people, you are able to zoom in on your mental images to give the features or objects a larger portion of your mental screen, much as you might physically move toward an object you wanted to observe more closely.

Now, look at the rabbit and the elephant and picture them both in your mind. Next, close your eyes and look at the elephant. Imagine walking toward the elephant, watching it as it gets closer to you. Do you find that there comes a point at which you can no longer see the rabbit or even all of the elephant? If you are like most people, you will find that the image of the elephant will appear to overflow the size of your image space. To "see" the whole elephant, you probably have to mentally zoom out again.

In another study, children in the first and fourth grades and adult college undergraduates were asked whether particular animals can be characterized as having various physical attributes (Kosslyn, 1976). Examples would include "Does a cat have claws?" and "Does a cat have a head?" In one condition, participants were asked to visualize each animal and to use their mental image in answering the questions. In the other condition, the participants were not asked to use mental images. It was presumed that they used verbal propositional knowledge to respond to the verbal questions.

In the imagery condition, all participants responded more quickly to questions about physical attributes that were larger than to questions about attributes that were smaller. For example, they might have been asked about a cat's head (larger) and a cat's claws (smaller). Different results were found in the nonimagery condition. In the nonimagery condition, fourth graders and adults responded more quickly to questions about physical attributes based on the distinctiveness of the characteristic for the animal. For example, they responded more quickly to questions about whether cats have claws (which are distinctive) than to questions about whether cats have heads (which are not particularly distinctive to cats alone). The physical size of the features did not have any effect on performance in the nonimagery condition for either fourth graders or adults.

Interestingly, first graders constantly responded more quickly regarding larger at tributes, not only in the imagery condition but also in the nonimagery condition. Many of these younger children indicated that they used imagery even when not instructed to do so. Furthermore, in both conditions, adults responded more quickly than did children. But the difference was much greater for the nonimagery condition than for the imagery condition. These findings support the functional equivalence

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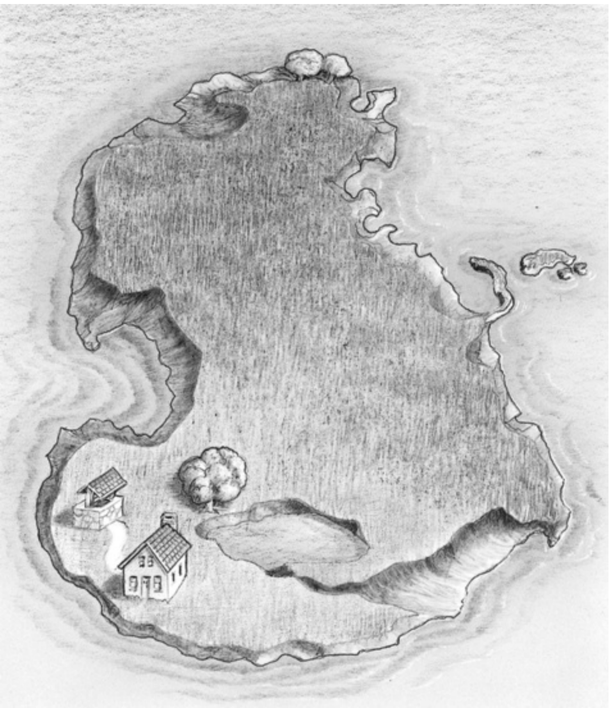
hypothesis: When we see something in front of our "mental eye," it takes children and adults about the same amount of time to perceive it, just as it would if we saw something in real life.

The findings also support the dual-code view in two ways. First, for adults and older children, responses based on the use of imagery (an imaginal code) differed from responses based on propositions (a symbolic code). Second, the development of propositional knowledge and ability does not occur at the same rate as the development of imaginal knowledge and ability. Children had not yet developed the propositional knowledge and therefore were slower than were adults in the nonimaginary condition. The distinction in the rate of development of each form of representation also seems to support Paivio's notion of two distinct codes.

Examining Objects: Image Scanning

Stephen Kosslyn has found additional support for his hypothesis that we use mental images in image scanning. The key idea underlying image scanning research is that images can be scanned in much the same way as physical percepts can be scanned. Furthermore, our strategies and responses for imaginal scanning should be the same as for perceptual scanning. A means of testing the functional equivalence of imaginal scanning is to observe some aspects of performance during perceptual scanning, and then compare that performance with performance during imaginal scanning.

For example, in perception, scanning across longer distances takes longer than scanning across shorter ones (Denis & Kosslyn, 1999; Maras et al., 2014). In one of Kosslyn's experiments, participants were shown a map of an imaginary island, which you can see in Figure 7.13 ■ (Kosslyn, Ball, & Reiser, 1978). The map shows various objects on the island, such as a hut, a tree, and a lake. Participants studied the map until they could



■ **Figure 7.13 Mental Scanning: An Imaginary Island.** Stephen Kosslyn and his colleagues (1983) used a map of an imaginary island with various landmarks to determine whether mental scanning across the image of a map was functionally equivalent to perceptual scanning of a perceived map.

reproduce it accurately from memory. Once the memorization phase of the experiment was completed, the critical phase began:

- Participants were instructed that, on hearing the name of an object read to them, they should imagine the map and mentally scan to the mentioned object.
- As soon as they arrived at the location of that object, they should press a key.
- An experimenter then read to the participants the names of objects.
- The participants had to scan to the proper location and press the button once they had found it.

This procedure was repeated a number of times. In each case, the participants mentally moved between various pairs of objects on successive trials. For each trial, the experimenter kept track of the participants' response times, indicating the amount of time it took them to scan from one object to another.

What did Kosslyn find? There was an almost-perfect linear relation between the distances separating pairs of objects in the mental map and the amount of time it took participants to press the button. The further away from each other the objects were, the longer it took participants to scan from one object to the other. Participants seem to have encoded the map in the form of an image. They actually scanned that image as needed for a response, just as they would have scanned a real map.

These findings have been replicated using other objects as well. In one study, Borst and Kosslyn (2008) presented participants with dots on a screen for a short time. In the mental image-scanning task, participants had to memorize the location of the dots before the trial. Once the dots had been presented, participants in the mental-image group were presented with an empty frame that contained only an arrow. They had to decide whether the arrow pointed at one of the dots they had seen previously. In another condition, the participants were presented with a frame that contained not only the arrow but also the dots. In all conditions, the time to make a judgment increased linearly, depending on the distance between the dot and the arrow.

This finding indicates that the same mechanisms were used, no matter whether participants looked at the actual dots presented with the arrow, or looked only at the arrow, needing to imagine the dots. If participants did not use a spatial representation but rather a code based on Pylyshyn's propositional theory (1973), then the distance between the points and the arrow should not have influenced reaction time, but it did. Recall that the experiment by Shepard and Metzler (1971) found linearly increasing reaction times for mental rotations as the angle of rotation increased.

Findings supporting an imaginal code have been shown in several other domains. For example, the same pattern of results has been obtained for scanning objects in three dimensions (Pinker, 1980). Specifically, participants observed and then mentally represented a 3-D array of objects—toys suspended in an open box—and then mentally scanned from one object to another.

One experiment compared mental scanning performance of participants with autism spectrum disorder (ASD) to that of participants without ASD. Although both groups showed similar performances, there were positive correlations between mental scanning and working memory as well as verbal IQ for the ASD group (but not for the group without ASD). This finding suggests that although both groups performed similarly well, they may have used different strategies to solve the scanning problems (Maras et al., 2014).

Representational Neglect

Additional evidence for the similarity between perception and mental imagery can be seen in cases of representational neglect. Many patients suffering from spatial neglect

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(see Chapter 4) also suffer from a related impairment called representational neglect. As noted earlier, in *spatial neglect*, a person ignores half of his or her visual field. In *representational neglect,* a person asked to imagine a scene and then describe it ignores half of the imagined scene. Although these two types of neglect often occur together, they can also occur independently. Peru and Zapparoli (1999) described a case of a woman who showed no evidence of spatial neglect while struggling with tasks that required the production of a mental image.

In another set of studies, an array was described to patients suffering from representational neglect. When the patients had to recall the array, they could not describe the left portion (Logie et al., 2005). Similarly, when subjects with representational neglect were presented with an image, they described the entire image. However, when the image was removed and they were asked to describe the image from memory, they failed to describe the left portion (Denis et al., 2002).

In scenes, representational neglect is present only when a vantage point is given (Rode et al., 2004). For example, if a person with representational neglect were asked to describe his or her kitchen, he or she would do so accurately. However, if the same person were asked to describe the kitchen from the refrigerator, then he or she would demonstrate neglect. It is likely that there exists complete knowledge of the scene, but that knowledge sometimes is not accessible when the patient generates a mental image.

CONCEPT CHECK

1. What is mental rotation?
2. What is some of the neuropsychological evidence for mental rotation?
3. What is image scaling?
4. How do we mentally scan images?
5. What is representational neglect?

Synthesizing Images and Propositions

In this chapter, we have discussed two opposing views of knowledge representation. One is a dual-code theory, suggesting that knowledge is represented both in images and in symbols. The second is a propositional theory, suggesting that knowledge is represented only in underlying propositions, not in the form of images, words, or other symbols.

In our discussion, we addressed the first three of Finke's criteria for imaginal representations. Mental imagery appears functionally equivalent to perception in many ways. This conclusion is based on studies of mental rotations, image scaling (sizing), and image scanning. The studies involving ambiguous figures and unfamiliar mental manipulations, however, suggest that there are limits to the analogy between perception and imagery.

Do Experimenters' Expectations Influence Experiment Outcomes?

Although evidence seems to be good for the existence of both propositions and mental images (Borst & Kosslyn, 2008; Kosslyn, Thompson, & Ganis, 2006; Pylyshyn, 2006), the debate is not over. Perhaps some of the confirmatory results found in image research

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could be the result of demand characteristics (i.e., subjects' perceptions of what is expected of them when they participate in an experiment; Intons-Peterson, 1983). Do experimenters' expectancies regarding the performance of participants on a particular task create an implicit demand for the participants to perform as expected?

Intons-Peterson (1983) set out to investigate just that question. She manipulated experimenter expectancies by suggesting to one group of experimenters that task performance would be expected to be better for perceptual tasks than for imaginal ones. She suggested the opposite outcome to a second group of experimenters. Would the different expectations of the experimenters lead to different performances of the participants? She found that experimenter expectancies did influence participants' responses in three tasks: image scanning, mental rotations, and another task comparing perceptual performance with imaginal performance.

When experimenters expected imaginal performance to be better than perceptual performance, participants responded accordingly, and vice versa. This result occurred even when the experimenters were not present while participants were responding and when the cues were presented via computer. Thus, experimental participants performing visualization tasks may be responding in part to the demand characteristics of the task. These demand characteristics result from the experimenters' expectations regarding the outcomes.

Other investigators responded to these findings (Jolicoeur & Kosslyn, 1985a, 1985b). In one experiment, participants were not asked to scan their mental images at all. However, they were asked two kinds of questions intermixed with each other: questions that involved responses requiring image scanning and questions that did not. Even when image scanning was not an implicit task demand, participants' responses to questions that required image scanning still showed a linear increase in response time if the subjects had to scan across a longer distance. When questions did not require image scanning, reaction time was always about the same, no matter what the focus of the question was.

In another set of experiments, Jolicoeur and Kosslyn used a map of an island, similar to the one presented in Figure 7.13, and again asked participants to imagine the map and scan from one location to another. They led their experimenters to expect a pattern of responses that would show a *U*-shaped curve, rather than a linear function. In this study, too, responses still showed a linear relation between distance and time. They did not show the *U*-shaped response pattern expected by the experimenters. Thus, the expectations of the experimenters did not influence the responses of the participants. The hypothesis regarding the functional equivalence of imagery and perception thus appears to have strong empirical support.

The debate between the propositional hypothesis and the functional equivalence (analogical) hypothesis has been suggested to be intractable, based on existing knowledge (Keane, 1994). For each empirical finding that supports the view that imagery is analogous to perception, a rationalist reinterpretation of the finding may be offered. The reinterpretation offers an alternative explanation of the finding. Although the rationalist alternative may be a less parsimonious explanation than the empiricist explanation, the alternative cannot be refuted outright. Therefore, the debate between the functional equivalence view and the propositional view may boil down to a debate between empiricism and rationalism.

Johnson-Laird's Mental Models

An alternative synthesis of the literature suggests that mental representations may take any of three forms: propositions, images, or mental models (Johnson-Laird, 1983, 1999; Johnson-Laird & Goldvarg, 1997). Here, propositions are fully abstracted representations of meaning that are verbally expressible. The criterion of the possibility of verbal expression distinguishes Johnson-Laird's view from that of other cognitive psychologists.

Mental models are knowledge structures that individuals construct to understand and explain their experiences (Brewer, 2003; Goodwin & Johnson-Laird, 2010; Johnson-Laird, 2001; Schaeken, Johnson-Laird, & D'Ydewalle, 1996; Tversky, 2000). The models are constrained by the individuals' implicit theories about these experiences, which can be more or less accurate. For example, you may have a mental model to account for how planes fly into the air. But the model depends—not on physical or other laws but rather—on your beliefs about them. The same would apply to the creation of mental models from text or symbolic reasoning problems as from accounts of planes flying in the air (Byrne, 1996; Ehrlich, 1996; Garnham & Oakhill, 1996).

"The cat is under the table" may be represented in several ways: as a proposition (because it is verbally expressible), as an image (of a particular cat in a particular position under a particular table), or as a mental model (of any cat and table).

Is there any proof for the use of mental models? In an experiment by Mani and Johnson-Laird (1982), some participants received precise location information for each object in a spatial array (determinate descriptions). Other participants received ambiguous location information for objects in the array (indeterminate descriptions). As an analogy, consider a relatively determinate description of the location of Washington, D.C.: It lies between Alexandria, Virginia, and Baltimore, Maryland; an indeterminate description of the location is that it lies between the Pacific Ocean and the Atlantic Ocean. When participants were given detailed (determinate) descriptions for the spatial layout of objects, they inferred additional spatial information not included in the descriptions, but they did not recall the verbatim details well. For example, they could infer additional geographic information about Washington, D.C.'s location, but they could not remember the description word for word. Their having inferred additional spatial information suggests that the participants formed a mental model of the information. That they then did not recall the verbatim descriptions very well suggests that they relied on the mental models. They did not rely on the verbal descriptions for their mental representations.

What do you think happened when participants were given ambiguous (indeterminate) descriptions for the spatial layout of objects? They seldom inferred spatial information not given in the descriptions, but they remembered the verbatim descriptions better than did the other participants. The authors suggested that participants did not infer a mental model for the indeterminate descriptions because of the multitude of possibilities for mental models of the given information. Instead, the participants appear to have mentally represented the descriptions as verbally expressible propositions. The notion of mental models as a form of knowledge representation has been applied to a broad range of cognitive phenomena. These phenomena include visual perception, memory, comprehension of text passages, and reasoning (Johnson-Laird, 1983, 1989). Consider, for example, the statement: "Some dogs are poodles." How might you construct a mental model to represent this statement?

Perhaps the use of mental models may offer a possible explanation of some findings that cannot be fully explained in terms of visual imagery. A series of experiments studied people who were born blind (Kerr, 1983). Because these participants have never experienced visual perception, we may assume that they never have formed visual images (at least, they have not done so in the ordinary sense of the term). Some of Kosslyn's tasks were adapted to work comparably for sighted and for blind participants (Kerr, 1983). For example, for a map-scanning task, the experimenter used a board with topographical features and landmarks that could be detected by using touch. She then asked participants to form a mental image of the board.

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Kerr asked participants to imagine various common objects of various sizes. The blind participants responded more slowly to all tasks than did the sighted participants. But Kerr's blind participants still showed similar response patterns to those of sighted participants. They showed faster response times when scanning shorter distances than when scanning longer distances. They also were faster when answering questions about images of larger objects than about images of smaller objects. At least in some respects, spatial imagery appears not to involve representations that are actual analogs to visual percepts.

The use of haptic (touch-based) "imagery" suggests alternative modalities for mental imagery. Haptic imagery has been explored further by a number of researchers. These researchers have found that haptic imagery shares a number of features with visual imagery. For instance, similar brain areas are active during both types of imagery (James et al., 2002; Zhang et al., 2004). Perhaps haptic imagery involves the formation of a mental model that is analogous, in some respects, to visual imagery.

Imaginal representation also may occur in an auditory modality (based on hearing). As an example, investigators found that participants seem to have auditory mental images, just as they have visual mental images (Intons-Peterson, Russell, & Dressel, 1992). Specifically, participants took longer mentally to shift a sound upward in pitch than downward. In particular, they were slower in going from the low-pitched purring of a cat to the high-pitched ringing of a telephone than in going from the cat's purring to a clock's ticking. The relative response times were analogous to the time needed physically to change sounds up or down in pitch. Consider what happened, in contrast, when individuals were asked to make psychophysical judgments involving discriminations between stimuli. Participants took longer to determine whether purring was lower pitched than was ticking (two relatively close stimuli) than to determine whether purring was lower pitched than was ringing (two relatively distant stimuli). As with haptic imagery, it is easier to conceptualize auditory imagery in terms of mental models than strictly in terms of the kinds of pictorial mental representations of which people speak when they think of visual imagery.

Psychophysical tests of auditory sensation and perception reveal findings analogous to the studies on auditory and haptic imagery. In another study, participants listened

practical applications of **COGNITIVE PSYCHOLOGY**

Dual Codes

How do you benefit from having a dual code for knowledge representation? Although a dual code may seem redundant and inefficient, having a code for analog physical and spatial features that is distinct from a code for symbolic propositional knowledge actually can be efficient. Consider how you learn material in your cognitive psychology course. Most people go to the lecture and obtain information from an instructor. They also read material from a textbook, as you are doing now. If you had only an analog code for knowledge representation, you would have a much harder time integrating the verbal information you received from your instructor in class with the printed information in your textbook. All your information would be in the form of auditory–visual images gleaned from listening to and watching your instructor in class and visual images of the words in your textbook. Thus, a symbolic code that is distinct from the analog features of encoding is helpful for integrating across different modes of knowledge acquisition.

Analog codes preserve important aspects of experience without interfering with underlying propositional information. For the purposes of performing well on a test, it is irrelevant whether the information was obtained in class or in the text; later, however, you may need to verify the source of information to prove that your answer is correct. In this case, analogical information might help.

Television used to be analog but now is largely digital. What are the advantages of digital television? Are there any potential disadvantages?

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to either familiar or unfamiliar songs with pieces of the song replaced with silence. Examining the brains of these participants revealed that there was more activation of the auditory cortex during silence when the song was familiar than when the song was unfamiliar (Kraemer et al., 2005). These findings suggest that when one generates an auditory image, the same brain areas as those involved in hearing are engaged.

Faulty mental models are responsible for many errors in thinking. Consider several examples (Brewer, 2003). Schoolchildren tend to think of heat and cold as moving through objects, much as fluids do. These children also believe that plants obtain their food from the ground and that boats made of iron should sink. Even adults have trouble understanding the trajectory of an object dropped from a moving airplane.

Experience is a useful tool for the repair of faulty mental models (Greene & Azevedo, 2007). In one study, faulty mental models concerning the process of respiration were explored. College students who made false predictions concerning the process of respiration participated in this study. These predictions were based on imprecise mental models. The experimenters set up a laboratory experience for the students to demonstrate and explore the process of respiration. One group stated their predictions before the experiment and another did not. Overall, participating in the activity improved the accuracy of the answers of participants to questions concerning respiration, compared with performance before the activity. When the students were required to state their predictions before the experiment, however, the improvement was even greater (Modell et al., 2000). This research can be applied to classroom teaching. For example, if a teacher asks students to explain how they think the respiratory system works and then offers an experiment or demonstration showing how respiration works, students who did not understand the process correctly are now more able, because of the activity, to correct their understanding and learn. Thus, experience can help correct faulty mental models. It is most helpful, however, when the faulty models are made explicit.

In sum, mental models provide an additional means of representation in addition to propositions and visual images. They are not mutually exclusive with these other two forms of representation, but they are complementary to them. Mental models provide a way of explaining empirical findings, such as haptic and auditory forms of imagery, which seem quite different from visual images.

Neuroscience: Evidence for Multiple Codes

Participants involved in a research project involving cognitive tasks can be influenced by the expectations of the researcher. But it seems implausible that such factors would equally influence the results of neuropsychological research. For example, suppose you remembered every word in Chapter 2 regarding which particular parts of your brain govern which kinds of perceptual and cognitive functions. (This is, of course, an unlikely assumption for you or for most participants in neuropsychological research.) How would you go about conforming to experimenters' expectations? You would have to control directly your brain's activities and functions so that you would simulate what experimenters expected in association with particular perceptual or cognitive functions. Likewise, brain-damaged patients do not know that particular lesions are supposed to lead to particular kinds of deficits. Indeed, the patients rarely know where a lesion is until after deficits are discovered. Thus, neuropsychological findings may circumvent many issues of demand characteristics in resolving the dual-code controversy. This research, however, does not eliminate experimenter biases regarding where to look for lesions or the deficits arising from them.

Left Brain or Right Brain: Where Is Information Manipulated?

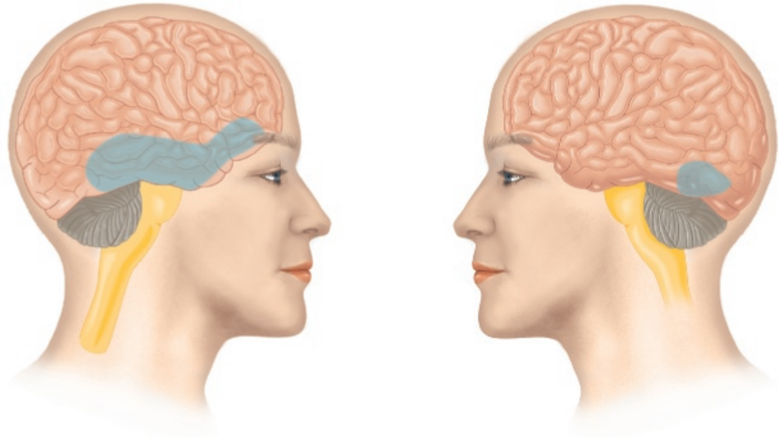
Initial neuropsychological research on imagery came from studies of patients with identified lesions and from split-brain patients. Recall the Chapter 2 studies of patients who underwent surgery that severed their right hemisphere from their left hemisphere. Researchers found that the right hemisphere appears to represent and manipulate visuospatial knowledge in a manner similar to perception (Gazzaniga & Sperry, 1967). In contrast, the left hemisphere appears to be more proficient in representing and manipulating verbal and other symbol-based knowledge.

Perhaps cerebral asymmetry has evolutionary origins (Corballis, 1989). The right hemisphere of the human brain represents knowledge in a manner that is analogous to our physical environment. This is also the case with the brains of other animals. Unlike the brains of other animals, however, the left hemisphere of the human brain has the ability to manipulate imaginal components and symbols and to generate entirely new information (e.g., consonant and vowel sounds and geometric shapes). For example, the word "text" as a verb did not exist just a few years ago. Today it exists and most people know what it means, that is, to send a text message. According to Corballis, humans alone can conceive what they have never perceived, although a review of the findings on lateralization has led to a modified view (Corballis, 1997). Specifically, recent neuropsychological studies of mental rotation in both animals and humans show that both hemispheres may be partially responsible for task performance. The apparent right-hemisphere dominance observed in humans may be the result of the overshadowing of left-hemisphere functions by linguistic abilities. Thus, it would be useful to have clear evidence of a cerebral-hemispheric dissociation between analog imagery functions and symbolic propositional functions. Scientists, however, will have to look deeper into brain functioning before this issue is resolved completely.

Two Kinds of Images: Visual versus Spatial

While examining visual imagery, researchers have found that images actually may be stored (represented) in different formats in the mind, depending on what kind of image is involved (Farah, 1988a, 1988b; Farah et al., 1988). Here, *visual imagery* refers to the use of images that represent visual characteristics such as colors and shapes. *Spatial imagery* refers to images that represent spatial features such as depth dimensions, distances, and orientations

Consider the case of L. H., who had a head injury at age 18. The injury resulted in lesions in the right and the left temporo-occipital regions, the right temporal lobe, and the right inferior frontal lobe. L. H.'s injuries implicated possible impairment of his ability to represent and manipulate both visual and spatial images. Figure 7.14 ■ shows those areas of L. H.'s brain where damage occurred.



■ **Figure 7.14 Damage to the Temporal Lobe.** Regions in which the brain of L. H. was damaged (see blue shaded area): the right temporal lobe and right inferior frontal lobe, as shown in the figure on the left; and the temporo-occipital region, as shown in the figure on the right.

Source: Based on Robert Solso, *Cognitive Psychology*, ed 6, p. 306. Copyright © 2000 Elsevier.

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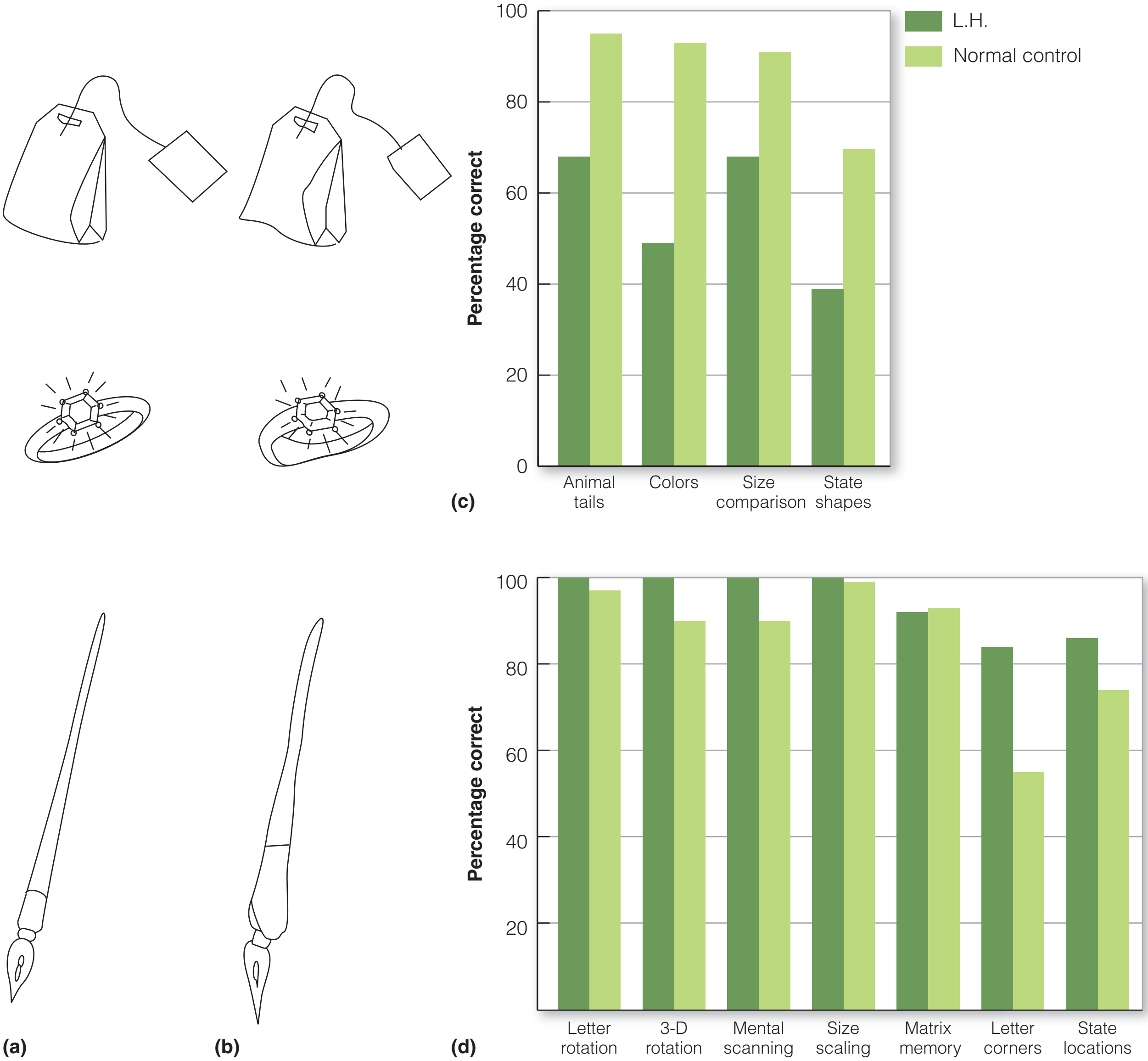

■ **Figure 7.15** **L. H.'s Performance in Visual and Spatial Imagery.** L. H. was able to draw accurately various objects. Panel (a) shows what he was shown, and panel (b) shows what he drew. However, he could not recognize the objects he copied. Despite L. H.'s severe deficits on visual imagery tasks (panel [c], regarding colors, sizes, and shapes), L. H. showed normal ability on spatial imagery tasks (panel [d], regarding rotations, scanning, and scaling).

Source: Based on M. J. Farah, K. M. Hammond, D. N. Levine, & R. Calvanio. Visual and spatial mental imagery: Dissociable systems of representation. *Cognitive Psychology*, 20, 439–462, © 1988.

Despite L. H.'s injuries, L. H.'s ability to see was intact. He was able satisfactorily to copy various pictures [Figure 7.15(a) ■ and (b) ■]. Nonetheless, he could not recognize any of the pictures he had copied. In other words, he could not link verbal labels to the objects pictured. He performed poorly when asked to respond verbally to questions requiring visual imagery, such as those regarding color or shape. Surprisingly, however, L. H. showed relatively normal abilities in several kinds of tasks, including the following: (1) rotations (2-D letters, 3-D objects); (2) mental scanning, size scaling, matrix

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memory, and letter corners; and (3) state locations [Figure 7.15(c) ■ and (d) ■]. That is, his ability for several types of spatial imagery was not impaired. This finding indicates that spatial and visual imagery may indeed be different from each other.

Investigators have also used event-related potentials (ERP; see Chapter 2, Table 2.3 ■) to study visual imagery. They thereby compared brain processes associated with visual perception to brain processes associated with visual imagery (Farah et al., 1988b). As you may recall, the primary visual cortex is located in the occipital region of the brain. During visual perception, ERPs generally are elevated in the occipital region. If visual imagery were analogous to visual perception, we could expect that, during tasks involving visual imagery, there would be analogous elevations of ERPs in the occipital region.

In Farah's study, ERPs were measured during a reading task. In one condition, participants were asked to read a list of concrete words (e.g., cat). In the other condition, participants were asked to read a comparable list of concrete words but also were asked to imagine the objects during reading. Each word was presented for 200 milliseconds. ERPs were recorded from the different sites in the occipital lobe and temporal lobe regions. The researchers found that the ERPs were similar across the two conditions during the first 450 milliseconds. After this time, however, participants in the imaginal condition showed greater neural activity in the occipital lobe than did participants in the nonimaginal (reading-only) condition. According to Farah et al., "Neurophysiological evidence suggests that our cognitive architecture includes representations of both the visual appearance of objects in terms of their form, color, and perspective, and of the spatial structure of objects in terms of their three dimensional layout in space" (1988a, p. 459). Knowledge of object labels (recognizing the objects by name) and attributes (answering questions about the characteristics of the objects) taps propositional, symbolic knowledge about the pictured objects. In contrast, the ability to manipulate the orientation (rotation) or the size of images taps imaginal, analogous knowledge of the objects. Thus, both forms of representation seem to answer particular kinds of questions for knowledge use.

✓ CONCEPT CHECK

1. Why are demand characteristics important when researchers design and interpret experiments?
2. What kind of mental model did Johnson-Laird propose?
3. What is the difference between visual and spatial imagery?

Spatial Cognition and Cognitive Maps

Most of the studies described thus far have involved the way in which we represent pictorial knowledge. The studies are based on what we have perceived by looking at and then imagining visual stimuli. Other research suggests that we may form imaginal maps based solely on our physical interactions with, and navigations through, our physical environment. This is true even when we never have a chance to "see the whole picture," as from an aerial photograph or a map. **Spatial cognition** deals with the acquisition, organization, and use of knowledge about objects and actions in 2-D and 3-D space.

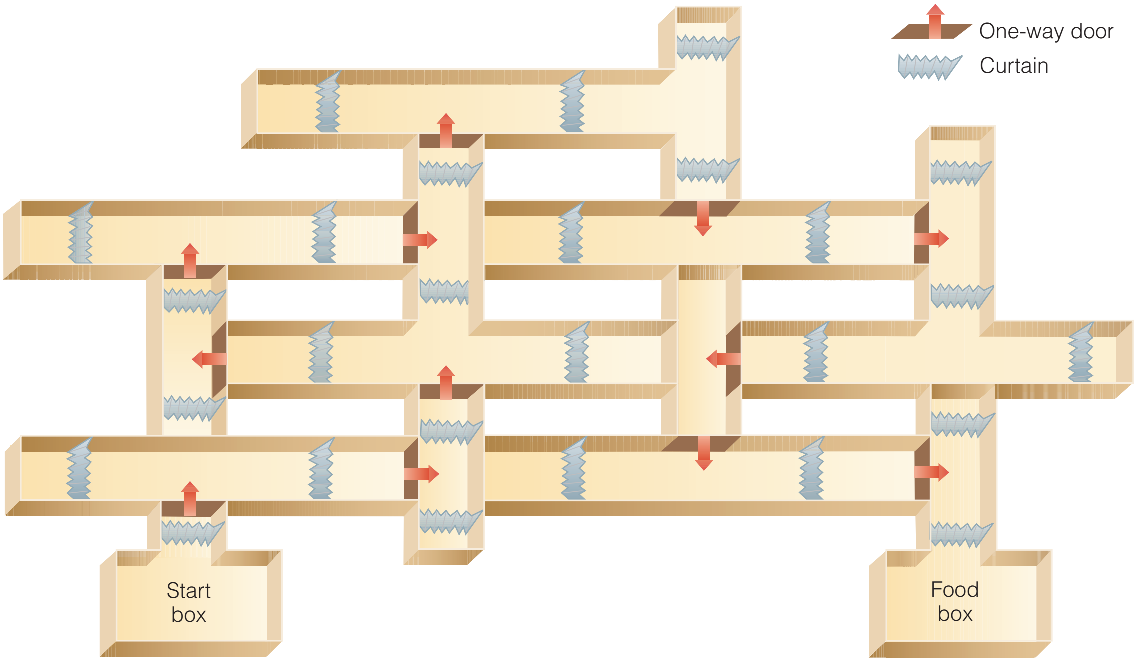
Cognitive maps are internal representations of our physical environment, particularly centering on spatial relationships. Cognitive maps seem to offer internal representations that simulate particular spatial features of our external environment (Rumelhart & Norman, 1988; Wagner, 2006).

Of Rats, Bees, Pigeons, and Humans

Some of the earliest work on cognitive maps was done by Edward Tolman during the 1930s. At this time, it was considered almost unseemly for psychologists to try to understand cognitive processes that could not be observed or measured directly (you can't look into a person's head and "see" the image that person is thinking about). In one study, the researchers were interested in the ability of rats to learn a maze (Figure 7.16 ■; Tolman & Honzik, 1930).

The rats were divided into three groups:

1. In the first group, the rats had to learn the maze. Their reward for getting from the start box to the end box was food. Eventually, these rats learned to run the maze without making any errors. In other words, they did not make wrong turns or follow blind alleys.
2. A second group of rats also was placed in the maze, but these rats received no reinforcement for successfully getting to the end box. Although their performance improved over time, they continued to make more errors than the reinforced group. These results are hardly surprising. We would expect the rewarded group to have more incentive to learn.
3. The third group of rats received no reward for 10 days of learning trials. On the 11th day, however, food was placed in the end box for the first time. With just one reinforcement, the rats' learning improved dramatically. These rats ran the maze about as well in fewer trials as the rats in the first group.



■ **Figure 7.16 Research on Mental Imagery in Rats.** Edward Tolman found that rats seemed to have formed a mental map of a maze during behavioral experiments.

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What, exactly, were the rats in Tolman and Honzik's experiment learning? It seems unlikely that they were learning simply "turn right here, turn left there," and so on. According to Tolman, the rats were learning a cognitive map, an internal representation of the maze. Through this argument, Tolman became one of the earliest cognitive theorists. He argued for the importance of the mental representations that give rise to behavior.

Decades later, even simple creatures were shown to be able to form some cognitive maps. These creatures may be able to translate imaginal representations into a primitive, prewired, analogical, and perhaps even symbolic form. For example, a Nobel Prize–winning German scientist studied the behavior of bees when they return to their hive after having located a source of nectar (von Frisch, 1962, 1967).

Apparently, bees not only can form imaginal maps for getting to food sources but also can use a somewhat symbolic form for communicating that information to other bees. Specifically, different patterns of dances can be used to represent different meanings. For example, a round dance indicates a source less than 100 yards from the hive. A figure-eight dance indicates a source at a greater distance. The details of the dance (e.g., in regard to wiggle patterns) differ from one species to another, but the basic dances appear to be the same across all species of bees. If the lowly bee appears able to imagine the route to nectar, what kinds of cognitive maps may be conceived in the minds of humans?

Homing pigeons are noted for their excellent cognitive maps. These birds are known for their ability to return to their home from distant locations. This quality made the birds useful for communication in ancient times and even in the 19th and 20th centuries. Extensive research has been completed on how pigeons form these maps. The left hippocampus plays a pivotal role in map formation. When the left hippocampus is lesioned, pigeons' ability to return to their homes is impaired. However, lesioning just any part of the hippocampus already impairs homing performance (Gagliardo et al., 2009). The left hippocampus is also crucial for the perception of landmarks within the environment (Bingman et al., 2003).

Other research suggests that the right hippocampus is involved in sensitivity to global features of the environment (e.g., geometry of the space). The hippocampus is involved in the formation of cognitive maps in humans as well (Iaria et al., 2008; Maguire, Frackowiak, & Frith, 1996).

Humans seem to use three types of knowledge when forming and using cognitive maps:

1. *Landmark* knowledge is information about particular features at a location and which may be based on both imaginal and propositional representations (Thorndyke, 1981).
2. *Route-road* knowledge involves specific pathways for moving from one location to another (Thorndyke & Hayes-Roth, 1982). It may be based on both procedural knowledge and declarative knowledge.
3. *Survey* knowledge involves estimated distances between landmarks, much as they might appear on survey maps (Thorndyke & Hayes-Roth, 1982). It may be represented imaginally or propositionally (e.g., in numerically specified distances).

Thus, people use both an analogical code and a propositional code for imaginal representations such as images of maps (McNamara, Hardy, & Hirtle, 1989; Russell & Ward, 1982).

According to a spatial-framework theory (Franklin & Tversky, 1990), when people construct a mental model of the space around them, they often orient themselves on their body along three axes: up–down, front–back, and left–right. Access to

BELIEVE IT OR NOT

Memory Test? Don't Compete with Chimpanzees!

Can you believe that chimpanzees' working memory for numbers is actually better than that of humans? Japanese researchers taught chimpanzees the numerals from 1 to 9. Then they devised experiments that displayed a number scattered on a touch screen. After a particular time interval, the numbers were replaced by white squares. Then, chimpanzees and human subjects had to touch the white squares in ascending numerical sequence. Young chimpanzees outperformed humans, both in speed and accuracy, suggesting that chimpanzees might actually have what is often called a *photographic memory* (Inoue & Matsuzawa, 2007).

Tetsuro Matsuzawa/Primate Research Institute

Chimpanzee Ayymu performing the masking task.

information is quickest along the up–down axis, followed by the front-back axis. People take longest to access information regarding the left–right axis. However, research has shown that the mere presence of another person often can lead people to change perspective and think differently about the spatial relations among the objects they perceive (Tversky & Hard, 2009).

Rules of Thumb for Using Our Mental Maps: Heuristics

When we use landmark, route-road, and survey knowledge, we sometimes use rules of thumb that influence our estimations of distance. These rules of thumb are cognitive strategies termed **heuristics**. For example, in regard to landmark knowledge, the more landmarks there are, the larger the distance we estimate (Thorndyke, 1981). In other words, as the density of intervening landmarks increases, the estimates of distance increase as well. Using this rule of thumb can lead to a distortion of our mental images, however. It has also been shown that people estimate the distance between two places to be shorter when traveling to a landmark than when traveling to a nonlandmark. That is, if you're traveling from a small town to the major city, the distance may seem smaller to you than when you're traveling from the big city to the small town (Tversky, 2005; Wagner, 2006).

In estimations of distances between particular physical locations (e.g., cities), route-road knowledge (knowledge of roads that connect towns or other particular locations) appears often to be weighted more heavily than survey knowledge (knowledge of the physical distance between two locations as the crow flies, that is regardless of whether a direct road connects the locations). This is true even when participants form a mental image based on looking at a map (McNamara, Ratcliff, & McKoon, 1984). Consider what happened when participants were asked to indicate whether particular cities had appeared on a map. They showed more rapid response times

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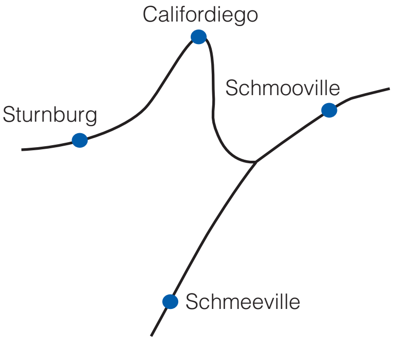
between names of cities when the two cities were closer together in route-road distance than when the two cities were physically closer together "as the crow flies" (Figure 7.17 ■).

Not only does route-road knowledge influence people's responses, but so does their knowledge of borders (a phenomenon called *border bias*). Mishra and Mishra (2010) conducted a study in which participants were asked to choose a vacation home from two choices located in two different states. They then were told that a volcano had erupted 200 miles from the location of both vacation homes (the volcano thus was located in between the two locations). The volcano was located in either one of the two states where the vacation homes were. Although the volcano's distance was the same from both vacation homes, participants were more than twice as likely (compared with a control condition) to choose the home in the state where the volcano was not located. In another study, they also rated the risk to their home state higher when a disaster was indicated in a neighboring state and the state borders were marked with a light, thin line as opposed to a thick line.



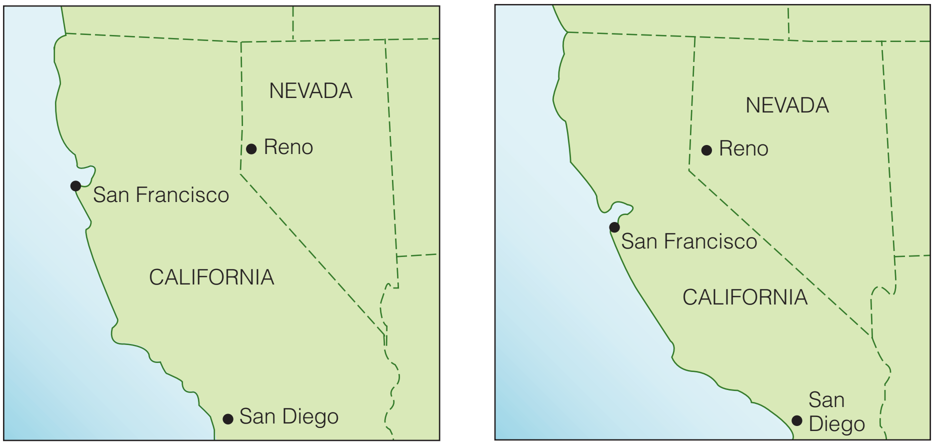
■ **Figure 7.17 Mental Maps.** Which city is closer to Sturnburg, Schmeeville or Schmooville? It appears that our use of cognitive maps often emphasizes the use of route-road knowledge, even when it contradicts survey knowledge.

Source: Based on Timothy R. McNamara, Roger Ratcliff, and Gail McKoon (1984), "The Mental Representation of Knowledge Acquired from Maps," *Journal of Experimental Psychology: LMC,* 10(4), 723–732. Copyright © 1984 by the American Psychological Association.

The use of heuristics in manipulating cognitive maps suggests that propositional knowledge affects imaginal knowledge (Tversky, 1981). This is so at least when people are solving problems and answering questions about images. In some situations, conceptual information seems to distort mental images. In these situations, propositional strategies may better explain people's responses than strategies that are based on a mental image. For example, a study by Friedman and Brown (2000; see also Friedman, Kerkman, & Brown, 2002 and Friedman & Montello, 2006) showed that when participants had to place cities on a map, those cities were clustered according to conceptual information like climate. The distortions seem to reflect a tendency to regularize features of mental maps. Thus, angles, lines, and shapes are represented as more like pure abstract geometric forms than they really are. Here are some examples:

1. *Right-angle bias:* People tend to think of intersections (e.g., street crossings) as forming 90-degree angles more often than the intersections really do (Moar & Bower, 1983; Smith & Cohen, 2008).
2. *Symmetry heuristic:* People tend to think of shapes (e.g., states or countries) as being more symmetrical than they really are (Montello et al., 2004; Tversky & Schiano, 1989)
3. *Rotation heuristic:* When representing figures and boundaries that are slightly slanted (i.e., oblique), people tend to distort the images as being either more vertical or more horizontal than they really are (Tversky, 1981, 1991; Wagner, 2006).
4. *Alignment heuristic:* People tend to represent landmarks and boundaries that are slightly out of alignment by distorting their mental images to be better aligned than they really are (i.e., we distort the way we line up a series of figures or objects; Tversky, 1981, 1991).
5. *Relative-position heuristic:* The relative positions of particular landmarks and boundaries is distorted in mental images in ways that more accurately reflect people's conceptual knowledge about the contexts in which the landmarks and boundaries are located, rather than reflecting the actual spatial configurations (Seizova-Cajic, 2003).

To see how the relative position heuristic might work, close your eyes and picture a map of the United States. Is Reno, Nevada, west of San Diego, California, or east of it? In a series of experiments, investigators asked participants questions such as this one



(a) **(b)**

■ **Figure 7.18** **The Relative Position Heuristic.** Which of these two maps, (a) or (b), more accurately depicts the relative positions of Reno, Nevada, and San Diego, California?

(Stevens & Coupe, 1978). They found that the large majority of people believe San Diego to be west of Reno. That is, for most of us, our mental map looks something like that in Figure 7.18(a) ■. Actually, however, Reno is west of San Diego. See the correct map in Figure 7.18(b) ■.

Some of these heuristics also affect our perception of space and of forms (Chapter 3). For example, the symmetry heuristic seems to be equally strong in memory and in perception (Tversky, 1991). Nonetheless, differences exist between perceptual processes and representational (imaginal or propositional) processes. For example, the relative position heuristic appears to influence mental representation much more strongly than it does perception (Tversky, 1991).

An additional factor when estimating the distances between cities is the number of landmarks or cities that are located in between the two target cities. When Thorndyke (1981) had participants estimate the distance between cities based on a map they had memorized, the estimated distance increased along with the number of identified intervening points between those cities.

Semantic or propositional knowledge (or beliefs) also can influence our imaginal representations of world maps (Saarinen, 1987; see also Louwerse & Zwaan, 2009). Specifically, students from 71 sites in 49 countries were asked to draw a sketch map of the world. Most students (even Asians) drew maps showing a Eurocentric view of the world. Many Americans drew Americentric views. A few others showed views centered on and highlighting their own countries (Figure 7.19 ■ shows an Australian-centered view of the world). In addition, most students showed modest distortions that enlarged the more prominent, well-known countries. They also diminished the sizes of less well-known countries (e.g., in Africa).

Finally, further work suggests that propositional knowledge about semantic categories may affect imaginal representations of maps. In one study, the researchers studied the influence of semantic clustering on estimations of distances (Hirtle & Mascolo, 1986). Hirtle's participants were shown a map of many buildings and then were asked to estimate distances between various pairs of buildings. They tended to distort the distances in the direction of guessing shorter distances for more similar landmarks and longer distances for less similar landmarks. Investigators found similar distortions in students' mental maps for the city in which they lived (Ann Arbor, Michigan; Hirtle & Jonides, 1985).

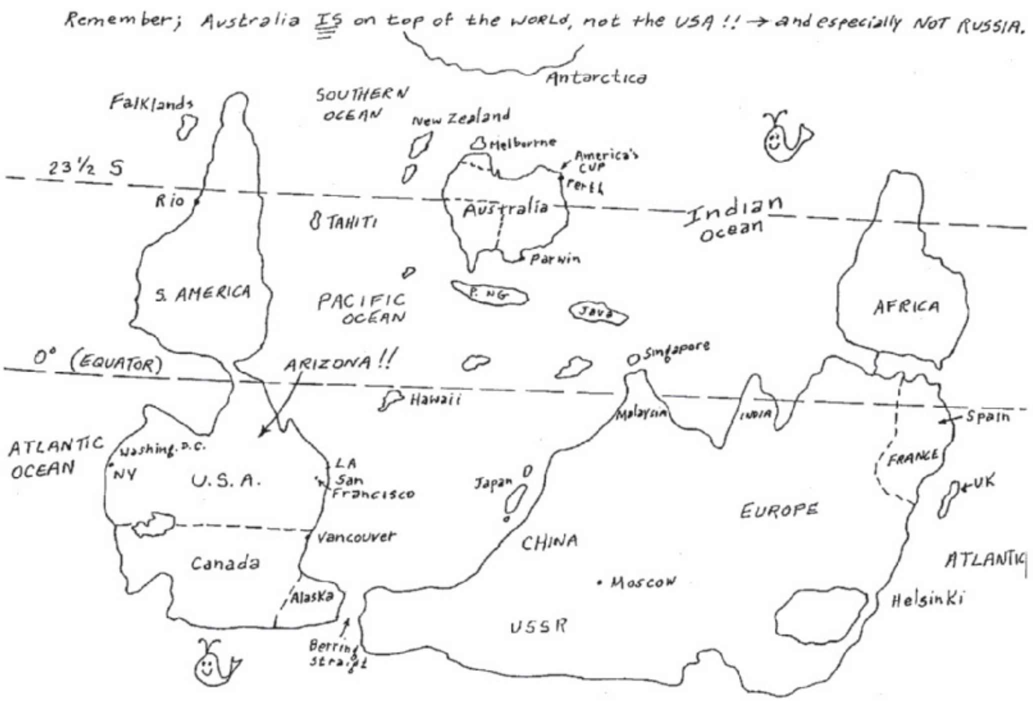

Remember; Australia IS on top of the WORLD, not the USA !! → and especially NOT RUSSIA.
Antarctica
Falklands
SOUTHERN OCEAN
New Zealand
Melbourne
America's CUP
Perth
23 ½ S
Rio
TAHITI
Australia
Indian Ocean
Darwin
P. NG
Java
S. AMERICA
PACIFIC OCEAN
AFRICA
0° (EQUATOR)
ARIZONA !!
Singapore
Hawaii
Malaysia
INDIA
Spain
ATLANTIC OCEAN
Washing. D.C.
NY
U.S.A.
LA
San Francisco
Japan
FRANCE
UK
EUROPE
Vancouver
CHINA
Canada
ATLANTIC
Moscow
Alaska
Helsinki
USSR
Berring strait

Figure 7.19 **Mental Representation of Maps.** Based on this Australian student's map, can you infer that this student mentally represents the world in the same way you do?

Source: From Solso, Robert L., *Cognitive Psychology,* Eighth Edition. Published by Allyn and Bacon, Boston, MA. Copyright © 2008 by Pearson Education. Reprinted by permission of the publisher.

INVESTIGATING COGNITIVE PSYCHOLOGY

Mental Maps

Which is larger in land area, India or Germany? If you are used to seeing the world in terms of the popular Mercator map, in which the map is flat and the equator is in the bottom half of the map, you might think that India and Germany are about the same size. In fact, you might think that Germany may be a bit larger than India.

Now look at a globe of the world. You will see that India is actually about five times as large as Germany. This is an example of how our cognitive maps may be based not in reality, but rather in our exposure to the topic and to our constructions and heuristics.

Neuropsychological work has shown that different brain areas are involved when we imagine things, depending on what exactly the content of our visual imagery is. As we have discussed, imagining a face involves the fusiform face area, whereas when imagining a scene associated with particular place, the parahippocampal place area is activated (O'Craven & Kanwisher, 2000). Imagining objects involves parietal areas concerned with visual-space analysis in both imagery and visual-perception (Boccia et al., 2015). But did you know that when we think about abstract maps like the ones discussed in this chapter, yet another brain area is involved as compared with our imagining concrete geographic places we know?

One study had some participants look at a map of Italy that showed eight cities. Other participants looked at a map of their university campus showing the location of

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eight landmarks. They were then asked to imagine the location of a city on the map or the location of a landmark from a given position in the center of campus. The difference between these two conditions is that imagining a city on a map is a relatively abstract task whereas imagining a concrete location on a campus from a certain position (say, the center green) on that campus involves navigational skills. In fact, the researchers found that for the condition involving the abstract map, mainly the left angular gyrus was activated. Conversely, for the condition involving navigational skills and including the concrete locations, areas needed for navigation (the retrosplenial complex and the parahippocampal gyrus) were activated (Boccia et al., 2014).

The work on cognitive maps shows once again how the study of mental imagery can help elucidate our understanding of human adaptation to the environment—that is, of human intelligence. To survive, we need to find our way around the environment in which we live. We need to get from one place to another. Sometimes, to get between places, we need to imagine the route we will need to traverse. Mental imagery provides a key basis for this adaptation. In some societies (Gladwin, 1970), the ability to navigate with the help of very few cues is a life or death issue. If sailors cannot do so, they eventually get lost and potentially die of dehydration or starvation. Thus, our imagery abilities are potential keys to our survival and to what makes us intelligent in our everyday lives.

Creating Maps from What You Hear: Text Maps

We have discussed the construction of cognitive maps based on procedural knowledge (e.g., following a particular route, as a rat in a maze), propositional information (e.g., using mental heuristics), and observation of a graphic map. In addition, we may be able to create cognitive maps from a verbal description (Taylor & Tversky, 1992a, 1992b; Tversky, 2005). These cognitive maps may be as accurate as those created from looking at a graphic map. Others have found similar results in studies of text comprehension (Glenberg, Meyer, & Lindem, 1987).

Tversky noted that her research involved having the readers envision themselves in an imaginal setting as participants, not as observers, in the scene. She wondered whether people might create and manipulate images differently when envisioning themselves in different settings. Specifically, Tversky wondered whether propositional information might play a stronger role in mental operations when we think about settings in which we are participants, as compared with settings in which we are observers. The studies reported in this chapter suggest that the construction of mental imagery may involve both: processes analogous to perception and processes relying on propositional representations.

Whether the debate regarding propositions versus imagery can be resolved in the terms in which it traditionally has been presented remains unclear. The various forms of mental representation sometimes are considered to be mutually exclusive. In other words, we think in terms of the question, “Which representation of information is correct?” Often, however, we create false dichotomies. We suggest that alternatives are mutually exclusive, when, in fact, they might be complementary. For example, models postulating mental imagery and those positing propositions can be seen in opposition, but this opposition is not necessary. Rather, it is in our construction of a relation. People possibly could use both representations. Propositional theorists might like to believe that all representations are fundamentally propositional. Quite possibly, however, both images and propositions are way stations toward some more basic and primitive form of representation in the mind of which we do not yet have any knowledge. A good case can be made in favor of both propositional and imaginal representations of knowledge. Neither is necessarily more basic than the other. The question we presently need to address is when we use which.

CONCEPT CHECK

1. What is a cognitive map?
2. Name some heuristics that people use when manipulating cognitive maps.
3. What is a text map?

Key Themes

This chapter illustrates some of the key themes mentioned in Chapter 1.

Structures versus processes. The debate regarding whether images are phenomenal or epiphenomenal hinges upon what kinds of mental structures are used to process stimuli. For example, when people mentally rotate objects, is the structural representation imaginal or propositional? Either kind of mental representation could generate processes that would enable people to see objects at different angular viewpoints. But the kinds of processes would be different—either mental manipulation of images or mental manipulation of propositions. To understand cognition, we need to understand how structures and processes interact.

Validity of causal inferences versus ecological validity. Suppose you wish to hire air-traffic controllers. Can you assess their mental-imagery and spatial visualization skills using paper-and-pencil tests of manipulation of geometric forms? Or do you need to test them in a setting that is more similar to that of air-traffic control, as through a simulation of the actual job? The paper-and-pencil test probably will yield more precise measurements, but will these measurements be valid? There is no final answer to the question. Researchers are studying this kind of question to understand how best to assess people's real-life skills.

Biological and behavioral methods. Early work by Stephen Kosslyn and his collaborators was all behavioral. The researchers investigated how people mentally manipulate various kinds of images. As time went by, the team started using biological techniques, such as fMRI, to supplement their behavioral studies. But they never saw the two kinds of research in opposition. Rather, they viewed them as wholly complementary, and do even today.

SUMMARY

1. **What are some of the major hypotheses regarding how knowledge is represented in the mind?** Knowledge representation includes the various ways in which our minds create and modify mental structures that stand for what we know about the world outside our minds.

   Knowledge representation involves both declarative (knowing that) and nondeclarative (knowing how) forms of knowledge. Through mental imagery, we create analog mental structures that stand for things that are not presently being sensed in the sense organs. Imagery may involve any of the senses, but the form of imagery most commonly reported by laypeople and most commonly studied by cognitive psychologists is visual imagery. Some studies (e.g., studies of blind participants and some studies of the brain) suggest that

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visual imagery itself may include two discrete systems of mental representation: One system involves nonspatial visual attributes, such as color and shape; another involves spatial attributes, such as location, orientation, and size or distance scaling.

According to Paivio's dual-code hypothesis, two discrete mental codes for representing knowledge exist. One code is for images and another for words and other symbols. Images are represented in a form analogous to the form we perceive through our senses. In contrast, words and concepts are encoded in a symbolic form, which is not analogical.

An alternative view of image representation is the propositional hypothesis. It suggests that both images and words are represented in a propositional form. The proposition retains the underlying meaning of either images or words, without any of the perceptual features of either. For example, the acoustic features of the sounds of the words are not stored, nor are the visual features of the colors or shapes of the images. Furthermore, propositional codes, more than imaginal codes, seem to influence mental representation when participants are shown ambiguous or abstract figures. Apparently, unless the context facilitates performance, the use of visual images does not always readily lead to successful performance on some tasks requiring mental manipulations of either abstract figures or ambiguous figures.

2. **What are some of the characteristics of mental imagery?** On the basis of a modification of the dual-code view, Shepard and others have espoused a functional equivalence hypothesis. This hypothesis asserts that images are represented in a form functionally equivalent to percepts, even if the images are not truly identical to percepts. Studies of mental rotations, image scaling, and image scanning suggest that imaginal task performance is functionally equivalent to perceptual task performance. Even performance on some tasks involving comparisons of auditory images seems to be functionally equivalent to performance on tasks involving comparisons of auditory percepts.

   Propositional codes seem less likely to influence mental representation than imaginal ones when participants are given an opportunity to create their own mental images. For example, they might do so in tasks involving image sizing or mental combinations of imaginal letters.

   Some researchers have suggested that experimenter expectancies may have influenced cognitive studies of imagery, but others have refuted these suggestions. In any case, neuropsychological studies are not subject to such influences. They seem to support the functional equivalence hypothesis by finding overlapping brain areas involved in visual perception and mental rotation.

3. **How does knowledge representation benefit from both images and propositions?** Kosslyn has synthesized these various hypotheses to suggest that images may involve both analogous and propositional forms of knowledge representation. In this case, both forms influence our mental representation and manipulation of images. Thus, some of what we know about images is represented in a form that is analogous to perception. Other things we know about images are represented in a propositional form. Johnson-Laird has proposed an alternative synthesis. He has suggested that knowledge may be represented as verbally expressible propositions, as somewhat abstracted analogical mental models, or as highly concrete and analogical mental images.

   Studies of split-brain patients and patients with lesions indicate some tendency toward hemispheric specialization. Visuospatial information may be

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processed primarily in the right hemisphere. Linguistic (symbolic) information may be processed primarily in the left hemisphere of right-handed individuals. A case study suggests that spatial imagery also may be processed in a different region of the brain than the regions in which other aspects of visual imagery are processed. Studies of normal participants show that visual-perception tasks seem to involve regions of the brain similar to the regions involved in visual-imagery tasks.

4. **How may conceptual knowledge and expectancies influence the way we use images?** People tend to distort their own mental maps in ways that regularize many features of the maps. For example, they may tend to imagine right angles, symmetrical forms, either vertical or horizontal boundaries (not oblique ones), and well-aligned figures and objects. People also tend to employ distortions of their mental maps in ways that support their propositional knowledge about various landmarks.

   They tend to cluster similar landmarks, to segregate dissimilar ones, and to modify relative positions to agree with conceptual knowledge about the landmarks. In addition, people tend to distort their mental maps. They increase their estimates regarding the distances between endpoints as the density of intervening land marks increases.

   Some of the heuristics that affect cognitive maps support the notion that propositional in formation influences imaginal representations. The influence of propositional information may be particularly potent when participants are not shown a graphic map. Instead, they are asked to read a narrative passage and to envision themselves as participants in a setting described in the narrative.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe some of the characteristics of pictures versus words as external forms of knowledge representation.
2. What factors might lead a person's mental model to be inaccurate with respect to how radio transmissions lead people to be able to hear music on a radio?
3. In what ways is mental imagery analogous (or functionally equivalent) perception?
4. In what ways do propositional forms of knowledge representation influence performance on tasks involving mental imagery?
5. Some people report never experiencing mental imagery, yet they are able to solve mental rotation problems. How might they solve such problems?
6. What are some practical applications of having two codes for knowledge representation? Give an example applied to your own experiences, such as applications to studying for examinations.
7. Based on the heuristics described in this chapter, what are some of the distortions that may be influencing your cognitive maps for places with which you are familiar (e.g., a college campus or your hometown)?

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KEY TERMS

analog codes, p. 253
cognitive maps, p. 280
declarative knowledge, p. 248
dual-code theory, p. 253
functional equivalence hypothesis, p. 261
heuristics, p. 282
imagery, p. 250
knowledge representation, p. 247
mental models, p. 274
mental rotation, p. 263
procedural knowledge, p. 248
propositional theory, p. 255
spatial cognition, p. 279
symbolic representation, p. 249

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 38—Mental Rotation
Lab 37—Link Word

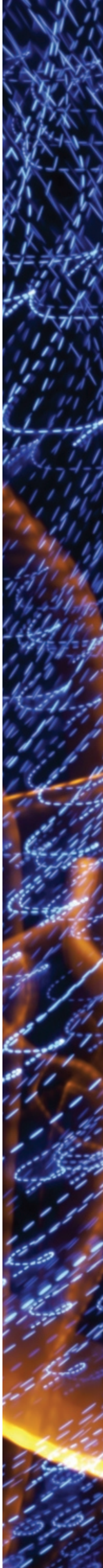
8

The Organization of Knowledge in the Mind

CHAPTER OUTLINE

Declarative versus Procedural Knowledge
Organization of Declarative Knowledge
  Concepts and Categories
    Feature-Based Concepts: A Defining View
    Prototype Theory: A Characteristic View
    A Synthesis: Combining Feature-Based and Prototype Theories
    Theory-Based View of Categorization
  Semantic-Network Models
    Collins and Quillian's Network Model
    Comparing Semantic Features
  Schematic Representations
    Schemas
    Scripts
Representations of How We Do Things: Procedural Knowledge
  The "Production" of Procedural Knowledge
  Nondeclarative Knowledge
Integrative Models for Representing Declarative and Nondeclarative Knowledge
  Combining Representations: ACT-R
    Declarative Knowledge within ACT-R
    Procedural Knowledge within ACT-R
  Parallel Processing: The Connectionist Model
    How the PDP Model Works
    Criticisms of the Connectionist Models
    Comparing Connectionist with Network Representations
  How Domain General or Domain Specific Is Cognition?
Key Themes
Summary
Thinking about Thinking: Analytical, Creative, and Practical Questions
Key Terms
Media Resources

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some of the questions we will explore in this chapter:

1. How are representations of words and symbols organized in the mind?
2. How do we represent other forms of knowledge in the mind?
3. How does declarative knowledge interact with procedural knowledge?

BELIEVE IT OR NOT The Savant in All of Us

People with autism who have an extraordinary ability have been called *autistic savants*. Their abilities often leave us incredulous—they can multiply large numbers within a fraction of a second, remember huge amounts of data, or can recall any detail with their photographic memory. But people who are autistic savants actually may not be that different from us.

Research suggests that we may all possess these talents, but they are part of low-level information processing that we normally do not use because we think at a higher level that is concept driven and allows for multisensory comparisons. For people who are autistic savants, this low-level processing comes automatically and naturally. Although we usually cannot consciously control our brain activity, studies have shown that people can learn to become sensitive to low-level processing and gain access to those early states of processing that are usually unconscious. This opens new possibilities for behavior and self-awareness (Birbaumer, 1999).

In this chapter, we'll learn about how we organize concepts in our minds and how these concepts help us think and to organize what we know.

John and Simon were college roommates and planned a trip to Arizona during spring break. They would be hiking through the remote Spike Leaf Canyon that hardly has been explored, was narrow, had lots of pools in which the water collects, and had smooth rock slides that connect the pools. Once they arrived at the canyon, they parked their car and began the hike to the edge, and from there followed a steep path down to the bottom. When they were almost at the bottom of the canyon, Simon suddenly tripped, fell over, and tumbled down the remainder of the steep slope. He was unable to stand up and feared he may have broken his ankle. Simon was in excruciating pain. John could not help him climb back up the narrow path, and because they were in such a remote desert area, they did not have any cell phone reception. John raced back the way they had come, got in the car, and frantically drove about half an hour until his cell phone worked so he could call for help. Eventually, a rescue team arrived at the canyon and carried Simon back up the canyon so he could receive treatment in the nearest hospital.

This story, which sounds just like an adventure story, actually raises a number of questions relevant to cognitive psychology. John panicked when he had to leave Simon behind and could not call for help immediately, and yet he managed to drive his car even though his thoughts were completely elsewhere. How did he do that? Fortunately, his procedural knowledge of how to drive a car was so good that he was able to drive automatically and did not have to concentrate on any details. He also was worried because canyons can flood quickly if it rains in a distant area upriver. Such flooding would be dangerous for his immobile friend. Therefore, John knew that he had to act fast, and he also knew how to make his cell phone work again and which number to call to get help when the phone started working.

Declarative versus Procedural Knowledge

Chapter 7, Mental Images and Propositions, described how knowledge may be represented in the form of propositions and images. This chapter explores how we organize knowledge so we can retrieve it when we need it. We expand this discussion to include various ways of organizing declarative knowledge that can be expressed in words and other symbols (i.e., “knowing that”). John knew he had to call 9-1-1 and that to do so he would need to get into an area with cell phone reception. Consider your own knowledge of facts about cognitive psychology, about world history, about your personal history, and about mathematics. Your knowledge in these areas relies on your mental organization of declarative knowledge.

In addition, this chapter describes a few of the models for representing procedural knowledge. Procedural knowledge is how to follow procedural steps for performing actions (i.e., “knowing how”). For example, your knowledge of how to drive a car, how to write your signature, how to ride a bicycle to the nearest grocery store, and how to catch a ball depends on your mental representation of procedural knowledge. Some theorists even have suggested integrative models for representing both declarative and procedural knowledge.

To get an idea of how declarative and procedural knowledge may interact, get paper and a pen or pencil. Try the demonstration in *Investigating Cognitive Psychology: Testing Your Declarative and Procedural Knowledge*.

INVESTIGATING COGNITIVE PSYCHOLOGY

Testing Your Declarative and Procedural Knowledge

As quickly and as legibly as possible, write your normal signature, from the first letter of your first name to the last letter of your last name. Don’t stop to think about which letters come next. Just write as quickly as possible.

Turn the paper over. As quickly and as legibly as possible, write your signature backward. Start with the last letter of your last name and work toward the first letter of your first name.

Now, compare the two signatures. Which signature was more easily and accurately created?

For both signatures, you had available extensive declarative knowledge of which letters preceded or followed one another. But for the first task, you also could call on procedural knowledge, based on years of knowing how to sign your name.

In addition to seeking to understand the *what* (the form or structure) of knowledge representation, cognitive psychologists also try to grasp the *how* (the processes) of knowledge representation and manipulation. Following are some of the questions we explore in this chapter:

- What are some of the general processes used to select and control the disorganized raw data available to us through our sense organs?
- How do we relate that sensory information to the information from internal sources of information (i.e., our memories and our thought processes)?

- How do we organize and reorganize our mental representations during various cognitive processes?
- What mental processes do we use to access and act on the knowledge we have in our minds?
- To what extent are these processes domain general, or common to multiple kinds of information, such as verbal and quantitative information?
- Conversely, to what extent are these processes domain-specific, or used only for particular kinds of information, such as verbal or quantitative information?

Knowledge representation and processing have been investigated by researchers from several disciplines, including cognitive psychologists, neuropsychologists, and computer scientists studying artificial intelligence (AI), which attempts to program machines to perform intelligently. The diverse approaches that researchers take when investigating knowledge representation promote exploration of a wide range of phenomena. They also encourage multiple perspectives of similar phenomena. Finally, they offer the strength of **converging operations**—the use of multiple approaches and techniques to address a problem.

Other than to satisfy their own idle curiosity, why do so many researchers want to understand how knowledge is represented? The way in which knowledge is represented profoundly influences how effectively knowledge can be manipulated for performing any number of cognitive tasks. To illustrate the influence of knowledge representation, try the following multiplication task using a representation in either Roman or Arabic numerals:

CMLIX   959
× LVIII   × 58

The two multiplication tasks are exactly the same, but representation in Roman numerals probably makes it much harder for you to compute the solution, doesn't it?

First, let's look at how declarative knowledge (concepts) is organized in our minds. We consider theories of how concepts can be grouped into categories as well as how they can be organized by means of semantic networks and schemas. Then we move on to the representation of procedural knowledge. And finally, we will explore models that try to combine the representation of declarative and procedural knowledge.

Organization of Declarative Knowledge

An idea about something that provides a means of understanding the world is a **concept**. A concept is the fundamental unit of symbolic knowledge, or knowledge of correspondence between symbols and their meaning. For example, the symbol "3" means *three* (Bruner, Goodnow, & Austin, 1956; Kruschke, 2003; Love, 2003). Often, a concept may be captured in a single word, such as *apple*. The concept *apple* includes information about just what an apple is, for example, color (red, green, or yellow), shape (rounded), and that it is a fruit (see also Figure 8.1 ■).

As you can imagine, people amass a large number of concepts over the course of their lives. How do they organize all those concepts? One way to organize them is by means of categories. A **category** is a hierarchy of concepts. A category is a concept with members. For example, bird is a concept, but it is also a category that has robin, blue jay,

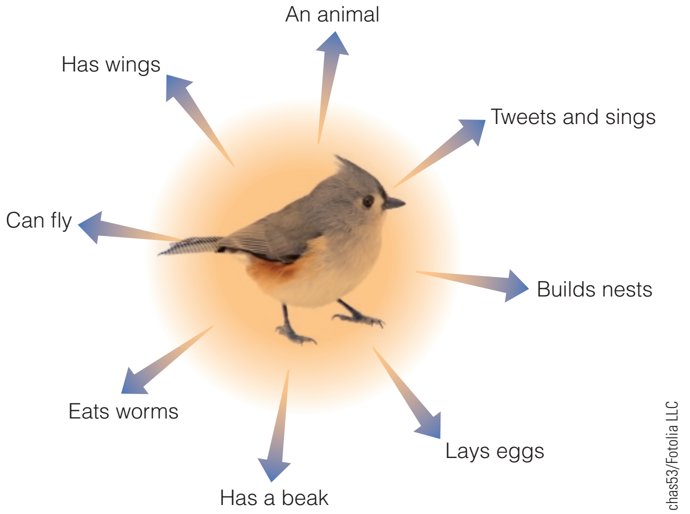

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Figure 8.1 The concept "bird" contains information about what makes an animal a bird: for example, that it builds nests, has wings, tweets, and so on.

and hawk as members. That is, a category is a group of items into which different objects or particular concepts can be placed that belong together because they share some common features, or because they are all similar to a certain prototype. So a bird is a concept, but it is also a category that includes, at a more specific level of the hierarchy, robin, bluebird, sparrow, and the like. At a more general level of the hierarchy, a bird is a kind of animal. Similarly, *red* is a concept. But it becomes a category when you consider more specific kinds of red, such as dark red, light red, reddish-brown, and so forth. The following section will discuss ways to organize concepts into categories. These ways include the use of defining features, prototypes, and exemplars.

Concepts and Categories

Categories can be subdivided in various ways. One commonly used distinction is between natural categories and artifact categories (Rhodes, Gelman, & Karuza, 2014). **Natural categories** are groupings that occur naturally in the world, like birds or trees. **Artifact categories** are groupings that are designed or invented by humans to serve particular purposes or functions, like automobiles and kitchen appliances. The speed it takes to assign objects to categories seems to be about the same for both natural and artifact categories (VanRullen & Thorpe, 2001). Many natural and artifact categories are relatively stable and people tend to agree on criteria for membership in them. A tiger is always a mammal, for example; and a knife is always a tool used for cutting.

Not all categories are stable, however (Dunbar, 2003; Thagard, 2003). Some categories are created to achieve goals in everyday life or for a specific purpose, for example, "my best friends," "things one can write on," or "things I need to purchase in the supermarket." These categories are called *ad hoc categories* (Barsalou, 1983; Sandberg, Sebastion, & Kiran, 2012). They typically are described not in words but rather in phrases. Their content varies, depending on the context. People in rural Uganda will probably name different things that you can write on than will urban Americans or Inuit Eskimos.

Concepts, in general, and categories in particular are also used in other areas like computer science. Developers try to develop algorithms that define "spam" so that e-mail programs can filter out unwanted messages and your mailbox is not flooded with them. Spammers, however, change the nature of their messages on a regular basis so that it is hard to create an algorithm that can catch all spam messages and can do so on a permanent basis (Fdez-Riverola, 2007). Computers thus face a challenge in recognizing members of the category *spam.*

Categories appear to have a **basic level** (sometimes termed a *natural level*) of specificity, a level within a hierarchy that is preferred to other levels (Medin, Proffitt, & Schwartz, 2000; Rosch, 1978). In this view, there is also a superordinate level and a subordinate level. Suppose we show you a red, roundish edible object that has a stem and that came from a tree. You might characterize on any of these levels:

- superordinate level: a fruit
- basic level: an apple
- subordinate level: a Red Delicious apple

Most people would characterize the object as an apple. The basic, preferred level of the category is *apple*. In general, the basic level is neither the most abstract nor the most specific. Of course, this basic level can be manipulated by context or expertise (Tanaka & Taylor, 1991). Suppose the object were held up at a fruit stand that sold only apples. You might describe it as a Red Delicious apple to distinguish it from the other apples around it.

How can we tell what the basic level is? Why is the basic level the *apple*, rather than *Red Delicious apple* or *fruit?* Or why is it *cow*, rather than *mammal* or *Guernsey?* Perhaps the basic level is the one that has the largest number of distinctive features that set it off from other concepts at the same level (Rosch et al., 1976). Thus, most of us would find more distinguishing features between an apple and a cow, say, than between a Red Delicious apple and a Pippin apple. Similarly, we would find few distinguishing features between a Guernsey cow and a Holstein cow. Again, not everyone necessarily would have the same basic level, as in the case of farmers. For our purposes, the basic level is the one that most people find to be maximally distinctive. By means of training, the basic level can be shifted to a more subordinate level (Scott et al., 2008). For example, the more a person learns about cars, the more he or she is likely to make elaborate distinctions among cars. Research suggests that the differences between experts and novices are not due to qualitatively different mechanisms but rather to quantitative differences in processing efficacy (Palmeri, Wong, & Gauthier, 2004; see also Mack et al., 2009).

When people are shown pictures of objects, they identify the objects at a basic level more quickly than they identify objects at higher or lower levels (Rosch et al., 1976). Objects appear to be recognized first in terms of their basic level. Only afterward are they classified in terms of higher or lower level categories. Thus, the picture of the roundish red, edible object from a tree probably first would be identified as an apple. Only then, if necessary, would it be identified as a fruit or a Red Delicious apple.

Now, how do people decide what objects to put into a category? Several theories try to explain this process. One theory suggests that we put an object only in one category if it has several defining features. Another approach proposes that we compare an object with an averaged representation (a prototype) to decide whether it fits into a category. Yet another is that people can categorize objects based on their own theories about those objects. We will explore these approaches in the next sections.

Feature-Based Concepts: A Defining View

The classic view of concepts disassembles a concept into a set of featural components. All those features are then necessary (and sufficient) to define the concept (Katz, 1972; Katz & Fodor, 1963). This means that each feature is an essential element of the concept. Together, the features uniquely define the concept; they are **defining features** (or necessary attributes): For a thing to be an *X*, it must have that feature. Otherwise, it is not an *X*.

Consider the concept *bachelor*. In addition to being human, a bachelor can be viewed as having three features: *male*, *unmarried*, and *adult*. The features are each singly necessary. If one feature is absent, the object cannot belong to the category. Thus, an unmarried male who is not an adult would not be a bachelor. We would not refer to a 12-year-old unmarried boy as a bachelor, because he is not an adult. Nor would we refer to just any male adult as a bachelor. If he is married, he is out of the running. An unmarried female adult is not a bachelor, either.

Moreover, the three features are jointly sufficient. If a person has all three features, then he is automatically a bachelor. According to this view, you cannot be male, unmarried, and an adult, and at the same time not be a bachelor. The feature-based view applies to more than bachelorhood, of course. For example, the term *wife* is made up of the features *married, female*, and *adult. Husband* is made up of the features *married, male*, and *adult*.

The feature-based view is especially common among linguists, those who study language (Clark & Clark, 1977; Finley & Badecker, 2009). This view is attractive because it makes concepts appear so orderly and systematic. Unfortunately, it does not work as well as it appears to at first glance. Some concepts do not readily lend themselves to featural analysis. *Game* is one such concept. Finding anything at all that is a common feature of all games is actually difficult to do (Wittgenstein, 1953). Some are fun; some are not. Some involve multiple players; others, such as solitaire, do not. Some are competitive; others, such as children's circle games (e.g., ring-around-the-rosy), are not. The more you consider the concept of a game, the more you begin to wonder whether anything at all holds the concept together. It is not clear that a game has any defining features at all. Nonetheless, we all know what we mean, or think we do, by the word *game*. Wittgenstein, therefore, has suggested that we know what is a game by means of *family resemblance*. According to him, not all games, or for that matter, objects in a particular category, share all of their defining features. Rather, this approach has some flexibility so that not all defining features have to be shared as long as category members do resemble each other in some way. Thus, a game is a concept whose category members share features, but without any particular feature being common to all members.

Another problem with the feature-based view is that a violation of those defining features does not seem to change the concept we use to define them. Consider a zebra (see Keil, 1989). Now suppose that someone painted a zebra all black. It then would be missing the critical attribute of stripes, but we still would call it a zebra. We run into the same problem with birds. We might think of the ability to fly as critical to being a bird. But certainly we would agree that a robin whose wings have been clipped is still a robin. So is an ostrich, which does not fly.

The examples of the robin and the ostrich point out another problem with the feature-based theory. Both a robin and an ostrich share the same defining features of birds. They are, therefore, birds. Loosely speaking, however, a robin seems somehow to be a better example of a bird than is an ostrich. Indeed, when people are asked to rate the typicality of a robin versus an ostrich as a bird, the robin virtually always will get a higher rating than the latter (Malt & Smith, 1984; Mervis, Catlin, & Rosch, 1976; Rosch, 1975). Children learn typical instances of a category earlier than they learn atypical ones (Rosch, 1978). Table 8.1 ■ shows some ratings of typicality for various instances of birds (Malt & Smith, 1984). Clearly, there are enormous differences, although the defining features are the same. On the 7-point scale used by Malt and Smith for ratings of the typicality of birds, *bat* received a rating of 1.53. This rating is despite the fact that a bat, strictly speaking, is not even a bird.

Table 8.1 **Typicality Ratings for Birds**

Barbara Malt and Edward Smith (1984) found enormous differences in the typicality ratings for various instances of birds (or birdlike animals).

Bird	Rating*	Bird	Rating
Robin	6.89	Sandpiper	4.47
Seagull	6.29	Chicken	3.95
Swallow	6.16	Flamingo	3.37
Falcon	5.74	Albatross	3.32
Starling	5.16	Penguin	2.63
Owl	5.00	Bat	1.63

*Ratings were made on a 7-point scale, with 7 corresponding to the highest typicality.

Source: After Malt & Smith, 1984. [Malt, B. C., & Smith, E. E. (1984). Correlated properties in natural categories. *Journal of Verbal Learning and Verbal Behavior,* 23, 250–269.]

In sum, the feature-based theory has some attractive features, but it does not give a complete account of concepts or categories. Some specific members of a category such as *bird* seem to be better examples than others. Yet, they all have the same defining features. The various examples, however, may be differentially typical of the concept of birds. Thus, we need a theory of knowledge representation that better characterizes how people truly represent knowledge.

Prototype Theory: A Characteristic View

Prototype theory takes a different approach: grouping things together not by their defining features but rather by their similarity to an averaged model of the category.

Prototypes and Characteristic Features A **prototype** is an abstract average of all the objects in the category we previously have encountered. That is, we have an average representation of the category, and we compare objects to that average representation (prototype) when making a decision whether or not to place them in a certain category. Objects that are prototypical of a category therefore have high family resemblance. Crucial for prototypes are **characteristic features**, which describe (characterize or typify) the prototype but are not necessary for it. Characteristic features commonly are present in typical examples of concepts, but they are not always present.

For example, consider the prototype of a game. It might include that it usually is enjoyable, has two or more players, and presents some degree of challenge. But a game does not have to be enjoyable. It does not have to have two or more players. And it does not have to be challenging. Similarly, a bird usually has wings and flies, but the prototype is just whatever game (or bird) represents the category best. This theory can handle the facts that (1) games seem to have no defining features at all and (2) a robin seems to be a better example of a bird than is an ostrich.

So what exactly is a characteristic feature? Whereas a defining feature is shared by every single object in a category, a characteristic feature need not be. Instead, many or most instances possess each characteristic feature. Thus, the ability to fly is typical of birds. But it is not a defining feature of a bird—an ostrich cannot fly. According to prototype theory, it thus seems less birdlike than a robin, which can fly. Similarly, a typical

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game may be enjoyable, but it need not be so. Indeed, when people are asked to list the features of a category, such as *fruit* or *furniture*, most list features like sweetness or "made out of wood." These features are characteristic rather than defining (Rosch & Mervis, 1975). You actually can compute a score that indicates how typical an instance is of its category by listing the properties typical of a concept, such as *fruit*, and then by assessing how many of those properties a given instance has (Rosch & Mervis, 1975). This matters in our interactions with other people as well: Stereotypes of different groups of people (e.g., Italians or psychologists) consist of a conglomerate of average features (Medin, 1989; see also Dolderer, Mummendey, & Rothermund, 2009).

■ To further explore prototype theory, see Lab 47, Prototypes, in CogLab.

Classical and Fuzzy Concepts Psychologists differentiate two kinds of concepts: *classical concepts* and *fuzzy concepts*. Classical concepts are categories that can be readily defined through defining features, such as *bachelor*. Fuzzy concepts are categories that cannot be so easily defined, such as *game* or *death*. Their borders are, as their name implies, fuzzy. Classical concepts tend to be inventions that experts have devised for arbitrarily labeling a class that has associated defining features. Fuzzy concepts tend to evolve naturally (Smith, 1988, 1995; see also Brent et al., 1996). Thus, the concept of a bachelor is an arbitrary concept we invented. Some experts may suggest that we use the word *fruit* to describe any part of a plant that has seeds, pulp, and skin. But our natural, fuzzy concept of fruit usually does not extend as easily to tomatoes, pumpkins, and cucumbers.

Classical concepts and categories may be built on defining features. Fuzzy concepts and categories are built around prototypes. According to the prototype view, an object will be classified as belonging to a category if it is sufficiently similar to the prototype, that is, if it has some family resemblance. Exactly what is meant by similarity to a prototype can be a complex issue, however. Different theories suggest how this similarity should be measured (Smith & Medin, 1981). For our purposes, we view similarity in terms of the number of features shared between an object and the prototype. Perhaps some features even should be weighed more heavily as being more central to the prototype than are other features (e.g., Komatsu, 1992).

Real-World Examples: Using Exemplars Some psychologists suggest that instead of using a single abstract prototype for categorizing a concept, we use multiple, specific exemplars. **Exemplars** are typical representatives of a category (Ross, 2000; Ross & Spalding, 1994). For example, in considering birds, we might think of the prototypical songbird, which is small, flies, builds nests, sings, and so on. We also might think of exemplars for birds of prey, for large flightless birds, for medium-size waterfowl, and so on. So although a prototype is an averaged representation of *all* the objects in a category, an exemplar is not necessarily averaged over all objects. Instead, there can be exemplars for different subtypes of objects within a category, like birds of prey and flightless birds. A penguin or ostrich can be a good exemplar within the category of birds (they exemplify the group of flightless birds), but they are not prototypical exemplars because those birds cannot fly.

Some investigators use this approach to explain how categories are both formed and used in speeded classification situations (Nosofsky & Palmeri, 1997; Nosofsky, Palmeri, & McKinley, 1994; see also Estes, 1994). In particular, categories are set up by creating a rule and then by storing examples as exemplars. Objects are then compared to the exemplars to decide whether or not they belong in the category the exemplars represent.

Exemplar theories of categorization also have been criticized. One notable criticism questions the number and types of exemplars that are stored for each

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category (Smith, 2005). Some theorists contend that the mind does not have enough resources to store all the exemplars one would need to typify membership in a category (Collier, 2005).

A recent theory called the *varying abstraction model* (VAM) suggests that prototypes and exemplars are just the two extremes on a continuum of abstraction. According to this theory, most of the time we do not use just one abstract prototype or a large number of concrete exemplars for categorization. Instead, we use a number of intermediate representations that represent subgroups within the category (Vanpaemel & Storms, 2008). For example, animals might be represented by specific exemplars of kinds of animals, such as finch or sparrow or whale, but also by higher order categories, such as songbird or marine mammal.

Some researchers do not support either an exclusive exemplar theory or an exclusive rule-based theory (Rouder & Ratcliff, 2004, 2006). Rather, they believe some combination of the two to be more appropriate. This idea is discussed in the next section.

A Synthesis: Combining Feature-Based and Prototype Theories

A full theory of categorization can combine both defining and characteristic features (see also Hampton, 1997; Poitrenaud, Richard, & Tijus, 2005; Smith, 1988; Smith, Shoben, & Rips, 1974; Wisniewski, 1997, 2000), so that each category has both a prototype and a core. A **core** refers to the defining features something must have to be considered an example of a category. The prototype encompasses the characteristic features that tend to be typical of an example (a bird can fly) but that are not necessary for being considered an example (an ostrich).

Consider the concept of a *robber*. The core requires that someone labeled as a robber be a person who takes things from others without permission. The prototype, however, tends to identify particular people as more likely to be robbers. Take, for example, white-collar criminals. Their crimes can include embezzling millions of dollars from their employers. These criminals are difficult to catch because they do not look like our prototypes of robbers, no matter how much they may steal from other people. In contrast, unkempt denizens of our inner cities sometimes are arrested for crimes they did not commit. In part, this occurs because they more closely match the commonly held prototype of a robber, regardless of whether or not they steal.

Two researchers tested the notion that we come to understand the importance of defining features only as we grow older (Keil & Batterman, 1984). Younger children, they hypothesized, view categories largely in terms of characteristic features. The investigators presented children between 5 and 10 years old with descriptions. Among them were two unusual individuals. The first was “a smelly, mean old man with a gun in his pocket who came to your house and took your TV set because your parents didn’t want it anymore and told him he could have it.” The second was “a very friendly and cheerful woman who gave you a hug, but then disconnected your toilet bowl and took it away without permission and with no intention to return it.” Younger children often characterized the first description as a better depiction of a robber than the second description. It was not until close to age 10 years old that children began to shift toward characterizing the second individual as more like a robber. In other words, the younger children viewed someone as a robber even if the person did not steal anything. What mattered was that the person had the characteristic features of a robber. This transition, however, is never fully complete. We might suspect that the first individual would be at least as likely to be arrested as the second. Thus, the issue of categorization itself remains somewhat fuzzy, but it appears to include some aspects of defining features and some aspects of prototypicality.

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BELIEVE IT OR NOT Some Numbers Are Odd, and Some Are Odder

Even classical concepts like that of an *odd number* seem to have prototypes (Armstrong, Gleitman, & Gleitman, 1983). The concept of an odd number is defined easily: An *odd number* is any integer not evenly divisible by 2. So how could one number be odder than another? People found different instances of this category to be more or less prototypical of odd numbers. For example, 7 and 13 are typical examples of odd numbers that are viewed as quite close to the prototype for an odd number. In contrast, 15 and 21 are not seen as so prototypically odd. In other words, people view 7 and 13 as better exemplars of odd numbers than 15 and 21. Nevertheless, all four numbers are actually odd.

Theory-Based View of Categorization

A departure from feature-based, prototype-based, and exemplar-based views of meaning is a theory-based view of meaning, also sometimes called an *explanation-based view.*

How Do People Use Their Theories for Categorization? A **theory-based view of meaning** holds that people understand and categorize concepts in terms of implicit theories, or general ideas they have regarding those concepts (Markman, 2003; Markman et al., 2007). For example, what makes someone a "good sport"?

- In the feature-based view, you would try to isolate features of a good sport.
- In the prototype view, you would try to find characteristic features of a good sport.
- In the exemplar view, you might try to find some good examples you have known in your life.
- In the theory-based view, you would use your experience to construct an explanation for what makes someone a good sport.

The theory-based view might go something like this: A good sport is someone who, when he or she wins, is gracious in victory and does not mock losers or otherwise make them feel bad about losing. It is also someone who, when he or she loses, loses graciously and does not blame the winner, the referee, or find excuses. Rather, he or she takes the defeat in stride, congratulates the winner, and then moves on. In the theory-based view, it is difficult to capture the essence of the theory in a word or two. Rather, the view of a concept is more complex.

The theory-based view suggests that people can distinguish between essential and incidental, or accidental, features of concepts because they have complex mental representations of these concepts. One study showed how such theories might manifest themselves in judgments about newly learned concepts (Rips, 1989). Participants received stories about a hypothetical creature. The stimuli were presented under two experimental conditions.

In this study (Rips, 1989), one condition involved a birdlike creature called a *sorp* that, through an accident, came to look like an insect. It was never stated that the sorp was birdlike or insect-like. Rather, the circumstances of the transformation were described in some detail. The sorp was described as having a diet consisting of seeds and berries, as having two wings and two legs, and as nesting high in the branches of a tree. The nest, like that of a bird, was composed of twigs and similar materials. Moreover, the sorp was covered with bluish-gray feathers, like many birds. But a particular sorp had a misfortune: Its nest was near the burial place of hazardous chemicals. As the chemicals contaminated the vegetation that the sorp ate, its appearance gradually started to change. The sorp lost its feathers and instead grew a new pair of wings that had a transparent membrane. The sorp left its nest and developed an outer shell that was brittle and iridescent. It grew two more pairs of legs, so that it now had six legs in all. It came to be able to hold on to smooth surfaces, and it started sustaining itself solely on the nectar of flowers. In due course, the sorp mated with another sorp, a normal female. The female laid the fertilized eggs that resulted from the mating in her nest and incubated them. After three weeks, normal young sorps emerged from their shells. In this description, the fact of the sorp's being able to mate with a normal sorp to produce normal sorps shows that the unfortunate sorp never really changed its basic biological makeup. It remained, in essence, a sorp.

The second condition involved an essential change in the nature of a creature. In other words, the change was one of essence rather than of accident and involved a creature known as a *doon*. During an early stage of the doon's life, it is known as a sorp. It has all the characteristics of a sorp (as previously described). But after a few months, the doon sheds its feathers and then develops the same characteristics that resulted from the unfortunate sorp's accident. In this second condition, the transformation is identical to that of the sorp described in the first condition, but the transformation is represented as a natural biological change rather than an accidental one caused by proximity to hazardous chemicals.

Participants in the study were asked to provide two ratings after reading about the sorp and the doon. The first rating was of the degree to which the sorp (in the sorp condition) or the doon (in the doon condition) fit into the category of "bird." The second rating was the similarity of the sorp or doon to birds. Thus, one rating was for category membership and the other for similarity.

Additionally, members in the control group read only the description of sorps. Control group participants were asked merely to rate the similarity of sorps to birds. They did not have to judge how well sorps fit into the category of "bird."

According to prototype and exemplar theories, there is no particular reason to expect the two sets of ratings from experimental participants to show different patterns. According to these theories, people categorize objects on the basis of their similarity to a prototype or an exemplar, so the results should be the same for both sets of ratings.

Now have a look at the results in Figure 8.2 ■. The results for the categorization and similarity ratings are dramatically different. When the sorp's features changed through an accident, it was still rated highly as belonging to the category of birds, although participants did not perceive them as very similar to birds. When the doon changed through a natural process, however, it was rated less highly as belonging to the category of birds although it seemed relatively similar to birds.

Control group participants had no trouble recognizing the similarity of the sorp to a bird. The difference in patterns between the category membership and similarity ratings is consistent with the theory-based view of meaning.

Finding the "Essence" of Things Further support for the theory-based view comes from work with children. A number of investigators have studied a view of meaning called *essentialism*. This view holds that certain categories, such as those of "lion" or "female," have an underlying reality that cannot be observed directly (Gelman, 2003, 2004). For example, someone could be a female even if another individual were incapable in his or her observations on the street of detecting that femaleness. One instance is having short hair. Having short hair might be more typical of males than females, yet females can have short hair. Essentialist beliefs about the characteristics of groups are often associated with the devaluation of these groups and increased prejudice (Bastian &

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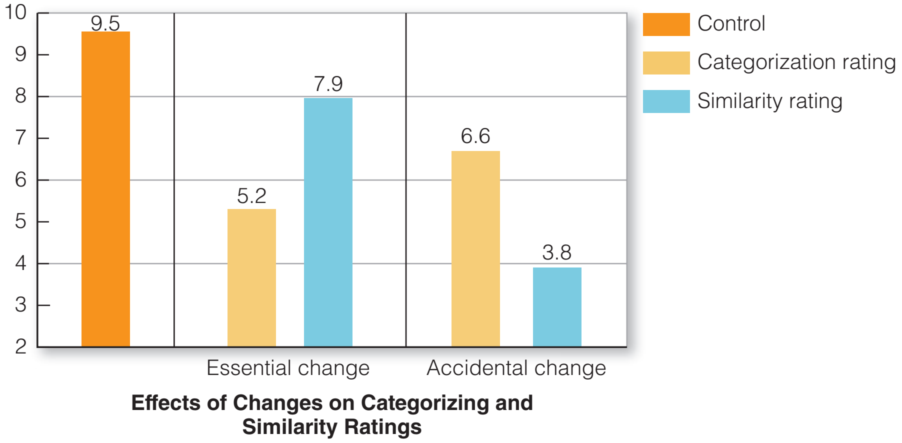


Figure 8.2 **Similarity Ratings.** Control group participants clearly thought sorps are very similar to birds. When the sorp's features changed through an accident, the sorp was still rated relatively highly as belonging to the category of birds although its rating for similarity to birds was low. When the sorp transformed through a natural process, however, its rating for belonging to the category of birds went down although it was judged as being quite similar to birds.

Source: Based on L. J. Rips, "Similarity, Typicality, and Categorization," in Vosniadou & Ortony (eds.), *Similarity and Analogical Reasoning,* pp. 21–59. Copyright © 1989 Cambridge University Press.

Haslam, 2006; Morton, Hornsey, & Postmes, 2009; Rangel & Keller, 2011). These beliefs suggest that members of a particular group are intrinsically one way and can't change; therefore, they cannot ever really belong to another group.

Gelman (2004, 2009) showed that even young children look beyond obvious features to understand the essential nature of things. This view contradicts Piaget's theory of cognitive development. According to that theory, children in the age range from roughly 8 to 11 years old are "concrete" thinkers. They cannot abstract features that are formal in nature. Yet, the work of psychologists studying essentialism suggest that young children can and do look for hidden features that are not obvious.

For example, in one study, 165 children ages 4 to 5 years were asked to make inferences about things like a tiger or gold (Gelman & Markman, 1986). The researchers found that even by age 4 years, children could make inferences using the abstract categories as opposed merely to perceptual similarity, even when these categories conflicted with appearances.

How people learn about concepts and categories depends, in part, on the tasks they need to do with those concepts and categories. For example, people learn about categories one way if they need to make classifications (e.g., "Is this particular animal a cat or a dog?") and another way if they need to make inferences (e.g., "If this animal is a dog, how many toes will it have?"; Yamauchi & Markman, 1998). Learning, therefore, is strategically flexible, depending on the task that the individual will have to do; it does not occur with a "one-size-fits-all" rigidity (Markman & Ross, 2003; Ross, 1997).

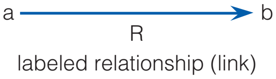
What all this means is that meaning is not just a matter of a set of features or exemplars. From the time children are very young, they start to form theories about the nature of objects. These theories develop with age. For example, you probably have a theory about what makes a car a car. You could see cars looking all kinds of strange ways. As long as they conformed to your theory, you nevertheless would label them as cars. Theories enable us to view meaning deeply rather than just to assign meaning on the basis of superficial features of objects.

Semantic-Network Models

Semantic-network models suggest that knowledge is represented in our minds in the form of concepts that are connected with each other in a web-like form. We will discuss a model developed by Collins and Quillian (1969) as well as another model that is based on a comparison of semantic features.

Collins and Quillian's Network Model

An older model still in use today is that knowledge is represented in terms of a hierarchical semantic (related to meaning as expressed in language—i.e., in linguistic symbols) network. A semantic network is a web of elements of meaning (nodes) in which the elements are connected with each other through links (Collins & Quillian, 1969; Marupaka, Iyer, & Minai, 2012). Organized knowledge representation takes the form of a hierarchical tree diagram. The elements are called **nodes**; they are typically concepts. The connections between the nodes are labeled *relationships*. They might indicate category membership (e.g., an "is a" relationship connecting "pig" to "mammal"), attributes (e.g., connecting "furry" to "mammal"), or some other semantic relationship. Thus, a network provides a means for organizing concepts. The exact form of a semantic network differs from one theory to another, but most **networks** look something like the highly simplified network shown in Figure 8.3 ■. The labeled relationships form links that enable the individual to connect the various nodes in a meaningful way.

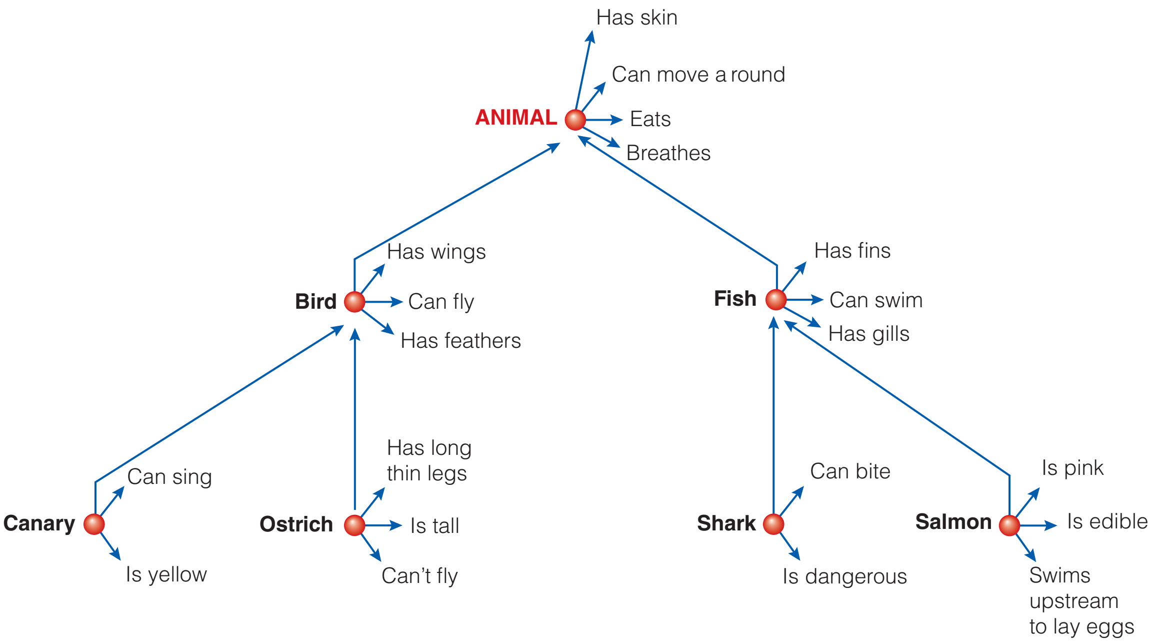


■ **Figure 8.3 Structure of a Semantic Network.** In a simple semantic network, nodes serve as junctures representing concepts linked by labeled relationships: a basic network structure showing that relationship R links the nodes a and b.

In a seminal study, the participants were given statements relating concepts, such as "A shark is a fish" and "A shark is an animal" (Collins & Quillian, 1969). They were asked to verify the truth of the statements. Some were true; others were not. As the object to be classified became more hierarchically remote from the category named in the statement, people generally took longer to verify a true statement. Thus, we could expect people to take longer to verify "A shark is an animal" than "A shark is a fish." The reason is that *fish* is an immediate superordinate category for *shark*. *Animal*, however, is a more remote superordinate category (see Figure 8.4 ■). Collins and Quillian concluded that a hierarchical network representation, such as the one shown in Figure 8.4, adequately accounted for the response times in their study.

A hierarchical model seemed ideal to the investigators. Within a hierarchy, we can efficiently store information that applies to all members of a category at the highest possible level in the hierarchy. We do not have to repeat the information at all of the lower levels in the hierarchy. Therefore, a hierarchical model provides a high degree of *cognitive economy*. The system allows for maximally efficient capacity use with a minimum of redundancy. Thus, if you know that dogs and cats are mammals, you store everything you know about mammals at the mammal level. For example, you might store that mammals have fur and give birth to live young whom they nurse. You do not have to repeat that information again at the hierarchically lower level for dogs and cats. Whatever was known about items at higher levels in a hierarchy was applied to all items at lower levels in the hierarchy. This concept of *inheritance* implies that lower level items inherit the properties of higher level items. This concept, in turn, is the key to the economy of hierarchical models. Computer models of the network clearly demonstrated the value of cognitive economy.

The Collins and Quillian study instigated a whole line of research into the structure of semantic networks. However, many of the psychologists who studied the Collins and Quillian data disagreed with Collins and Quillian's interpretations. For one thing, the model could not explain numerous anomalies in the data. For example, participants take longer to verify "a lion is a mammal" than to verify "a lion is an animal." Yet, in a strictly hierarchical view, verification should be faster for the mammal statement than for the


Has skin
Can move a round
ANIMAL
Eats
Breathes
Has wings
Bird
Can fly
Has feathers
Has fins
Fish
Can swim
Has gills
Has long thin legs
Can sing
Canary
Is yellow
Ostrich
Is tall
Can't fly
Can bite
Shark
Is dangerous
Is pink
Salmon
Is edible
Swims upstream to lay eggs

■ **Figure 8.4 Hierarchical Structure of a Semantic Network.** A semantic network has a hierarchical structure. The concepts (represented through the nodes; in color) are connected by means of relationships (arrows) like "is" or "has." As you move up within the network along the lines, you can retrieve additional properties of the concepts. For example, if you move upward from "salmon" to "fish," you get the additional information that a salmon has fins, gills, and can swim.

Source: Based on *In Search of the Human Mind,* by Robert J. Sternberg. Copyright © 1995 by Harcourt Brace & Company.

animal one. After all, the category *mammal* is hierarchically closer to the category *lion* than is the category *animal*.

Comparing Semantic Features

An alternative theory is that knowledge is organized based on a comparison of semantic features, rather than on a strict hierarchy of concepts (Smith, Shoben, & Rips, 1974). Although this theory sounds similar to the feature-based theory of categorization, it differs from it in a key way: Features of different concepts are compared directly, rather than serving as the basis for forming a category. Consider the categorization of different mammals. In the feature-based theory, each mammal would be described by its own set of defining features—a rabbit might be defined by its fur, long ears, and hopping walk. If features are compared directly, then you would compare all mammals on the basis of the same set of features. How does this work?

Let's stick with the mammal example. Mammal names can be represented in terms of a psychological space organized by three features: size, ferocity, and humanness (Henley, 1969). A lion, for example, would be high in all three. An elephant would be particularly high in size but not so high in ferocity. A rat would be small in size but relatively high in ferocity. Figure 8.5 ■ shows how information might be organized within a nonhierarchical feature-based theory. This representation, too, leaves a number of questions unanswered. For example, how does the word *mammal* fit in? It does not seem to fit into the space of mammal names. Where would other kinds of objects fit?

Neither of the preceding two theories of representation completely specifies how all information might be organized in a semantic network. For example, how are parts of a

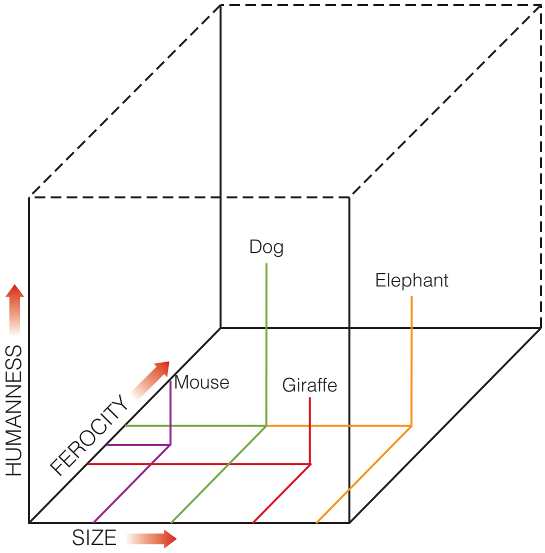


Figure 8.5 Comparison of Semantic Features. One alternative to hierarchical network models of semantic memory involves representations highlighting the comparison of semantic features. The features model, too, fails to explain all the data regarding semantic memory.

	Ferocity	Size	Humanness
Mouse	4	2	2
Dog	5	4.5	5
Giraffe	3	7	2
Elephant	5	9	4

whole represented in the network? Perhaps some kind of combination of representations is used (e.g., Collins & Loftus, 1975). Other network models tend to emphasize mental relationships that we think about more frequently rather than just any hierarchical relationships. For example, they might emphasize the link between birds and robins or sparrows or the link between birds and flying. They would not emphasize the link between birds and turkeys or penguins or the link between birds and standing on two legs.

A common method for examining semantic networks involves the use of word-stem completion. In this task, participants are presented a prime for a very short amount of time and then are given the first few letters of a word and told to complete the stem with the first word that comes to mind. The stems could be completed with a semantically related word or any number of unrelated words. Normally, participants complete these stems with a semantically related item. For example, complete the following word:

s _ _ m

How did you complete it? Many people, after reading this paragraph, would complete it with "stem." But many other possibilities could complete it that were not primed, such as "spam," "slim," "slum," and "sham," to name a few.

These findings are taken to mean that the activation of one node of the network increases the activation of related nodes. One study noted that with the progression of Alzheimer's disease, the activation of related nodes is impaired. As a result, the word stems for patients with Alzheimer's disease more frequently are completed with words that are unrelated to the prime (Passafiume, Di Giacomo, & Carolei, 2006).

Semantic networks also were explored with the patient H. M. (see Chapter 5 for information on H. M.). As you may recall, the late H. M.'s hippocampus was lesioned as a treatment for epilepsy. A side effect of this treatment was a great loss in the ability to form new memories. However, H. M. was capable of learning at least some new semantic

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information. Although performance on semantic tasks was impaired in H. M., clearly some semantic learning took place (O'Kane, Kensinger, & Corkin, 2004). Although semantic learning can occur without the involvement of the hippocampus, these findings indicate that such learning is greatly improved by its use.

We may broaden our understanding of concepts further if we consider not only the hierarchical and basic levels of a concept (Komatsu, 1992) but also other relational information the concept contains. Specifically, we may better understand the ways in which we derive meanings from concepts by considering their relations with other concepts, as well as the relations among attributes contained within a concept. For example, new multimedia learning and instruction devices that are based on semantic network models and use tools like mind-mapping can indeed increase knowledge acquisition (Zumbach, 2009).

Schematic Representations

Another way to organize the many concepts we have in our minds is by schemas. First we will discuss schemas in general and then have a look at scripts, which are a particular kind of schema.

Schemas

One main approach to understanding how concepts are related in the mind is through **schemas**. They are similar to semantic networks, except that schemas often are more task-oriented. Recall that a schema is a mental framework for organizing knowledge. It creates a meaningful structure of related concepts. For example, we might have a schema for a kitchen that tells us the kinds of things one might find in a kitchen and where we might find them. Of course, both concepts and schemas may be viewed at many levels of analysis. It all depends on the mind of the individual and the context (Barsalou, 2000; Koppel & Berntsen, 2014). Imagine your mother has a bad backache and you offer to give her a *massage*. Massage to you may mean rubbing her back and perhaps kneading her shoulders. For a massage therapist, *massage* may encompass much more. He distinguishes different muscles and tendons in the back and recognizes that a backache also may be related to a condition in the hips or elsewhere in the body. Thus, he targets his treatment much more specifically. Similarly, most people do not have an elaborate schema for *cognitive psychology*. For most cognitive psychologists, however, the schema for *cognitive psychology* is richly elaborated. It encompasses many subschemas, such as subschemas for attention, memory, and perception. Schemas have several characteristics that ensure wide flexibility in their use (Rumelhart & Ortony, 1977; Thorndyke, 1984):

1. Schemas can include other schemas. For example, a schema for animals includes a schema for cows, a schema for apes, and so on.
2. Schemas encompass typical, general facts that can vary slightly from one specific instance to another. For example, although the schema for mammals includes a general fact that mammals typically have fur, it allows for humans, who are less hairy than most other mammals. It also allows for porcupines, which seem more prickly than furry, and for marine mammals like whales that have just a few bristly hairs.
3. Schemas can vary in their degree of abstraction. For example, a schema for justice is much more abstract than a schema for apple or even a schema for fruit.

Schemas also can include information about relationships (Komatsu, 1992). Some of this information includes relationships among the following:

- concepts (e.g., the link between trucks and cars);
- attributes within concepts (e.g., the height and the weight of an elephant);

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- attributes in related concepts (e.g., the redness of a cherry and the redness of an apple);
- concepts and particular contexts (e.g., fish and the ocean); and
- specific concepts and general background knowledge (e.g., concepts about particular U.S. presidents and general knowledge about the U.S. government and about U.S. history).

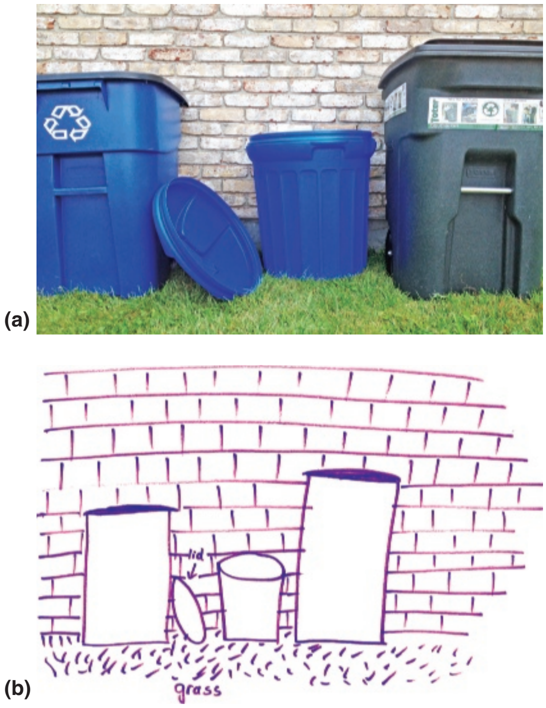
Relationships within schemas that particularly interest cognitive psychologists are causal (if–then) relationships. For example, consider our schema for *glass*. It probably specifies that if an object made of glass falls onto a hard surface, the object may break. Schemas also include information that we can use as a basis for drawing inferences in novel situations. For instance, suppose that a 75-year-old woman, a 45-year-old man, a 30-year-old nun, and a 25-year-old woman are sitting on park benches surrounding a playground. A young child falls from some playground equipment. He calls out "Mama!" To whom is the child calling? Chances are that, to determine your answer, you would be able to draw an inference by calling on various schemas. They would include ones for mothers, for men and women, for people of various ages, and even for people who join religious orders.

Researchers interested in AI have adapted the notion of schemas to fit various computer models of human intelligence. These researchers devised computer models of how knowledge is represented and used. Schemas can be used, for example, when conducting searches in large and complex databases or to integrate masses of information (Do & Rahm, 2007; Fagin et al., 2009).

Schemas also influence our memories of the scenes we perceive and store in our memory. When we remember a certain scene (e.g., a photograph we have seen), we extend the boundaries of what we have seen and incorporate information in our memory of details that were actually just outside the boundaries of what we saw (see Figure 8.6 ■ for an example). In Figure 8.6(a), for instance, you see a photo of trashcans in front of

■ Figure 8.6 Boundary Extension. When presented with a scene like the one in Figure 8.6(a), people may extend the boundaries of that scene in their minds and remember details they had not actually seen (Figure 8.6[b]). This is called boundary extension.

Source: Hubbard, T. L., Hutchison, J. L., & Courtney, J. R. (2010). Boundary extension: Findings and theories. *Quarterly Journal of Experimental Psychology, 63*(8), 1467–1494.



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a fence. But when asked to draw the scene you saw, you may end up drawing a picture that looks like the one depicted in Figure 8.6(b) in which the fence to the left and right has been added and the bottoms of the lid and trash cans have been added. This is called *boundary extension* (Hubbard, Hutchison, & Courtney, 2010).

A problem with schemas is that they can give rise to stereotypes. For example, we might have a schema for the kind of person we believe was responsible for the destruction of the World Trade Center on September 11, 2001. This schema can easily generate a stereotype of certain groups of people as likely terrorists. If you associate a certain type of clothing or a particular belief system with the terrorists, for instance, you may easily associate other people with the group of perpetrators just because they happen to wear the same kind of clothing or share some of the beliefs of the terrorists.

Scripts

One particular kind of schema is a script (Schank & Abelson, 1977). A **script** contains information about the particular order in which things occur. In general, scripts are much less flexible than schemas. Scripts, however, include default values for the actors, the props, the setting, and the sequence of events expected to occur. These values taken together compose an overview of an event.

Think about a restaurant script. The script may be applied to one particular kind of restaurant—for example, a coffee shop. A script has several features:

- *props*: tables, a menu, food, a check, and money
- *roles* to be played: a customer, a waiter, a cook, a cashier, and an owner
- *opening conditions* for the script: the customer is hungry, and he or she has money
- *scenes*: entering, ordering, eating, and exiting
- a set of *results*: the customer has less money; the owner has more money; the customer is no longer hungry; and sometimes the customer and the owner are pleased

Various empirical studies have been conducted to test the validity of the script notion. In one, researchers presented their participants with 18 brief stories (Bower, Black, & Turner, 1979). You can read one of these, representing the doctor's office script, in *Investigating Cognitive Psychology: Scripts—The Doctor.*

INVESTIGATING COGNITIVE PSYCHOLOGY

Scripts—The Doctor

John was feeling bad today and decided to go see the family doctor. He checked in with the doctor's receptionist and then looked through several medical magazines that were on the table by his chair. Finally, the nurse came and asked John to take off his clothes. The doctor was very nice to him. He eventually prescribed some pills for John. Then John left the doctor's office and headed home.

Did John take off his clothes?

This "scripted" description of a visit to a doctor's office is fairly typical. Notice that in this description, as would probably happen in any verbal description of a script, some details are missing. The speaker (or scriptwriter, in this case) may have omitted mentioning these details. Thus, we do not know for sure that John actually took off his clothes. Moreover, the nurse probably beckoned John at some point. She or he then escorted John to an examination room and probably took John's temperature and his blood pressure and weighed him. The doctor probably asked John to describe his symptoms, and so on. But we do not know any of these things for sure.

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In the research, participants were asked to read 18 stories similar to the one in the *Investigating Cognitive Psychology* box. Later, they were asked to perform one of two tasks. In a recall task, participants were asked to recall as much as they could about each of the stories. Here, participants showed a significant tendency to recall, as parts of the stories, elements that were not actually in the stories but that were parts of the scripts that the stories represented. In the recognition task, participants were presented with sentences. They were asked to rate, on a 7-point scale, their confidence that they had seen each of the sentences. Some of the sentences were from the stories; others were not. Of the sentences that were *not* from the stories, some were from the relevant scripts, and others were not from these scripts. Participants were more likely to characterize particular nonstory sentences as having come from the stories if the nonstory sentences were script-relevant than if the nonstory sentences were not script relevant. The Bower, Black, and Turner (1979) research suggested that scripts seem to guide what people recall and recognize—ultimately, what people know. Likewise, we also have life scripts that include events that typically happen during one's lifetime. When researchers asked participants to remember fictional life stories, participants best remembered high-frequency events (ones that most people would include in their list of typical life events) like marriage and going to college, whereas they had a harder time remembering low-frequency events like a divorce (Koppel & Berntsen, 2014).

Scripts also may come into play in regard to the ways in which experts converse with and write for one another. Certainly, experts share a **jargon**—specialized vocabulary commonly used within a group, such as a profession or a trade. You may overhear psychologists engrossed in a discussion about priming effects, but a layperson likely will not understand what they are talking about exactly. In addition to their jargon, however, experts share a common understanding of scripts that are known by insiders to the field of expertise. For example, after reading Chapter 2, you have a basic understanding of positron emission tomography (PET) methods. Therefore, when someone mentions that a PET scan was used to examine the brain, you have an idea of what happened. People outside the area of expertise do not share this understanding. In the PET example, a person who has never read or learned about PET scans might know that the result was an image of the brain but would not know that the procedure involved the injection of a slightly radioactive form of oxygen. When trying to understand technical manuals and technical conversations outside your area of expertise, you may run into vocabulary difficulties and information gaps. You lack the proper script for interpreting the language being spoken

Imaging studies reveal that the frontal and parietal lobes are involved in the generation of scripts (Godbout et al., 2004). The generation of scripts requires a great deal of working memory. Further script generation involves the use of both temporal and spatial information.

A number of patient populations experience impaired script use. For instance, people with schizophrenia frequently have trouble recalling and sequencing scripts. Also, these people add events to a script that should not be included. Research indicates a relationship between difficulties with script processing and the positive symptoms of schizophrenia (like hallucinations and illusions) on the one hand, and dysfunction of the frontal lobes, on the other hand (Matsui et al., 2006). People with attention deficit hyperactivity disorder (ADHD), people with autistic-spectrum disorders, and even people who are aging normally also may experience problems with scripts and may have trouble recalling the proper sequence of the steps involved in scripts (Allain et al., 2007; Braun et al., 2004; Loth, Gómez, & Happé, 2008). Again, the frontal lobes seem to play a central role in script generation and use.

The *typicality effect* is an interesting effect in script learning. In general, when a person is learning a script, if both typical and atypical actions are provided, the atypical information will be recalled more readily. This difference is likely due to the increased

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effort in processing required for atypical information as compared with typical information. When someone suffers from a closed-head injury, like a strong blow to the head, the typicality effect disappears (Vakil et al., 2002). In other words, people then have roughly equal recall of typical and atypical information.

In people with aphasia, the typicality effect also is affected. Interestingly, the degree of an individual's semantic impairment influences whether the typicality effect weakens in ad hoc categories or in well-defined categories: People with high levels of semantic impairment show the typicality effect only for well-defined categories whereas people with a less severe semantic impairment exhibit the typicality effect only for ad hoc categories (Sandberg, Sebastian, & Kiran, 2012).

practical applications of **COGNITIVE PSYCHOLOGY**

Scripts in Your Everyday Life

Take a closer look at the scripts you use in your everyday life. Is your going-to-class script different from your going-to-meals script or other scripted activities? In what ways do your scripts differ—in structure or in details? Try making changes to your script, either in details or in structure and see how things work. For example, you may find that you rush in the morning to get to school or work and forget things or arrive late. Aside from the obvious adjustment of getting up earlier, analyze the structure of your script. See if you can combine or remove steps. You could try laying out your clothes and packing your backpack or briefcase the night before to simplify your morning routine. The bottom line? The best way to make your scripts work better for you is first to analyze what they are and then to correct them.

Are the scripts in your life always useful, or are there some that interfere with your getting things done?

The script model has helped cognitive psychologists gain insight into knowledge organization. Scripts enable us to use a mental framework for acting in certain situations when we must fill in apparent gaps within a given context. Without access to mental scripts, we probably would be at a loss the first time we entered a new restaurant or a new doctor's office. Imagine what it would be like if the nurse at the doctor's office had to explain each step to you. When everyone in a given situation follows a similar script, the day flows much more smoothly.

Whether we subscribe to the notion of categories, semantic networks, or schemas, the important issue is that knowledge is organized. These forms of organization can serve different purposes. The most adaptive and flexible use of knowledge would allow us to use any form of organization, depending on the situation. We need some means to define aspects of the situation, to relate these concepts to other concepts and categories, and to select the appropriate course of action, given the situation. Next, we discuss theories about how the mind represents procedural knowledge.

CONCEPT CHECK

1. What is a concept?
2. What is a category?
3. What is the difference between prototypes and exemplars?
4. What is the theory based view of meaning?
5. What are the components of a semantic network?
6. What is a schema?
7. Why do we need scripts?

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Representations of How We Do Things: Procedural Knowledge

Some of the earliest models for representing procedural knowledge (how we do things) come from AI and computer simulation research (see Chapter 1). Through these models, researchers try to get computers to perform tasks intelligently, particularly in ways that simulate human intelligence. In fact, cognitive psychologists have learned a great deal about representing and using procedural knowledge. Through trial-and-error attempts at getting computers to simulate intelligent cognitive processes, cognitive psychologists have come to understand some of the complexities of human information processing. The next section describes how psychologists believe procedural knowledge "works." Afterward, we will look at some research on the brain and how it influenced theories and models.

The "Production" of Procedural Knowledge

Procedural knowledge representation is acquired by practicing the implementation of a procedure. It is not merely a result of reading, hearing, or otherwise acquiring information from explicit instructions. Once a mental representation of nondeclarative knowledge is constructed (proceduralization is complete) that knowledge is implicit. It is hard to make explicit by trying to put it in words. In fact, practice often decreases explicit access to that knowledge. For example, suppose you recently have learned how to drive a standard shift car. You may find it easier to describe how to do so than someone who learned that skill long ago. As your explicit access to nondeclarative knowledge decreases, however, your speed and ease of gaining implicit access to that knowledge increases. Eventually, most nondeclarative knowledge can be retrieved for use much more quickly than declarative knowledge can be retrieved.

Psychologists have developed a variety of models for how procedural information is represented and processed. Each of these models involves the **serial processing** of information, in which information is handled through a linear sequence of operations, one operation at a time. One way in which computers can represent and organize procedural knowledge is in the form of sets of rules governing a **production**, which includes the generation and output of a procedure (Jones & Ritter, 2003). Computer simulations of productions follow production rules (if–then rules), including an "if" clause and a "then" clause (Newell & Simon, 1972). People may use this same form of organizing knowledge or something close to it. For example, suppose your car is veering toward the left side of the road. Then you should steer toward the right side of the road if you wished to avoid hitting the curb. The "if" clause includes a set of conditions that must be met to implement the "then" clause. The "then" clause is an action or a series of actions that are a response to the "if" clause.

For a given if–then rule, each condition may contain one or more variables. For each of these conditions, there may be one or more possibilities. For example, *if* you want to go somewhere by car, and *if* you know how to drive a car, and *if* you are licensed and insured to drive, and *if* you have a car available to you, and *if* you do not have other constraints (e.g., no keys, no gas, broken engine, dead battery), *then* you may execute the actions for driving a car somewhere.

When the rules are described precisely and all the relevant conditions and actions are noted, a huge number of rules are required to perform even a simple task. These rules are organized into a structure of *routines* (instructions regarding procedures for implementing a task) and *subroutines* (instructions for implementing a subtask within a larger task governed by a routine). Many of these routines and subroutines are *iterative*, meaning that they are repeated many times during the performance of a task.

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If you want to complete a particular task or use a skill, you use a **production system** that includes the entire set of rules (productions) for executing the task or using the skill (Anderson, 1983, 1993; Gugerty, 2007; Newell & Simon, 1972; Simon, 1999a, 1999b).

Consider an example of a simple production system for a pedestrian to cross the street at an intersection with a traffic light (Newell & Simon, 1972). It is shown here (with the "if" clauses indicated to the left of the arrows and the "then" clauses indicated to the right of the arrows):

traffic light red → stop

traffic light green → move

move and left foot on pavement → step with right foot

move and right foot on pavement → step with left foot

In this production system, the individual first tests to see whether the light is red. If it is red, the person stops and again tests to see whether the light is red. This sequence is repeated until the light turns green. At that point, the person starts moving. If the person is moving and the left foot is on the pavement, the person will step with the right foot. If the person is moving and the right foot is on the pavement, the person will step with the left foot.

Sometimes, production systems, like computer programs, contain bugs. *Bugs* are flaws in the instructions for the conditions or for executing the actions. For example, in the cross-the-street program, if the last line read "move and right foot on pavement → step with right foot," the individual executing the production system would get nowhere. According to the production system model, human representations of procedural knowledge may contain some occasional bugs (Gugerty, 2007; VanLehn, 1990).

Until about the mid-1970s, researchers interested in knowledge representation followed one of two basic strands of research: procedural knowledge or declarative knowledge. AI and information-processing researchers were refining various models for representing procedural knowledge. Cognitive psychologists and other researchers were considering various alternative models for representing declarative knowledge. By the end of the 1970s, integrative models of knowledge representation began to emerge.

Nondeclarative Knowledge

As mentioned previously, knowledge traditionally has been described as either declarative or procedural. One can expand the traditional distinction between declarative and procedural knowledge to suggest that nondeclarative knowledge may encompass a broader range of mental representations than just procedural knowledge (Squire, 1986; Squire et al., 1990). Specifically, in addition to declarative knowledge, we mentally represent the following forms of nondeclarative knowledge:

- perceptual, motor, and cognitive skills (procedural knowledge)
- simple associative knowledge (classical and operant conditioning)
- simple nonassociative knowledge (habituation and sensitization)
- priming (fundamental links within a knowledge network, in which the activation of information along a particular mental pathway facilitates the subsequent retrieval of information along a related pathway or even the same mental pathway; see Chapter 4)

All of these nondeclarative forms of knowledge are usually implicit. You are not aware of the different steps you carry out when you act, and it is hard for you to spell them out explicitly.

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INVESTIGATING COGNITIVE PSYCHOLOGY

Procedural Knowledge

Ask a friend whether he or she would like to win $20. The $20 can be won if your friend can recite the months of the year within 30 seconds—in alphabetical order. Go!

In the years that we have offered this cash to the students in our courses, not a single student has ever won, so your $20 is probably safe. This demonstration shows how something as common and frequently used as the months of the year is bundled together in a certain order. It is difficult to rearrange their names in an order that is different from their commonly used or more familiar order.

Squire's primary inspiration for his model came from three sources: his own work; a wide range of neuropsychological research done by others, including studies of amnesic patients and animal studies; and human cognitive experiments. Consider an example: Work with amnesic patients reveals clear distinctions between the neural systems for representing declarative knowledge versus neural systems for some of the nondeclarative forms of knowledge. For instance, amnesic patients often continue to show procedural knowledge even when they cannot remember that they possess such knowledge. They often show improvements in performance on tasks requiring skills. These improvements indicate some form of new knowledge representation, despite an inability to remember ever having had previous experience with the tasks. For example, an amnesic patient who is given repeated practice in reading mirror writing will improve as a result of practice, but he or she will not recall ever having engaged in the practice (Baddeley, 1989).

Another paradox of human knowledge representation also is demonstrated by amnesics. Although amnesics do not show normal memory abilities under most circumstances, they do show the priming effect. Recall from Chapter 4 that, in priming, particular cues and stimuli seem to activate mental pathways, which in turn enhance the retrieval or cognitive processing of related information. For example, if someone asks you to spell the word *sight*, you will probably spell it differently, depending on several factors. These factors include whether you have been primed to think about sensory modalities ("sight"), about locations for an archaeological dig ("site"), or about lists of references ("cite"). When amnesic participants have no recall of the priming and cannot explicitly recall the experience during which priming occurred, priming still affects their performance.

Try the experiment on priming in *Investigating Cognitive Psychology: Priming*. It requires you to draw on your store of declarative knowledge.

The preceding examples illustrate situations in which an item may prime another item that is somehow related in meaning. We actually may differentiate two types of priming: semantic priming and repetition priming (Pesciarelli et al., 2007; Posner et al., 1988). In semantic priming, we are primed by a meaningful context or by meaningful information. Such information typically is a word or cue that is meaningfully related to the target that is used. Examples are fruits or green things, which may prime *lime*. In repetition priming, a prior exposure to a word or other stimulus primes a subsequent retrieval of that information. For example, hearing the word *lime* primes subsequent stimulation for the word *lime*. Both types of priming have generated a great deal of research, but semantic priming often particularly interests cognitive psychologists.

According to spreading activation theories, the amount of activation between a prime and a given target node is a function of two things: the number of links connecting the

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INVESTIGATING COGNITIVE PSYCHOLOGY

Priming

Recruit at least two (and preferably more) volunteers. Separate them into two groups. For one group, ask them to unscramble the following anagrams (puzzles in which you must figure out the correct order of letters to make a sensible word): ZAZIP, GASPETHIT, POCH YUSE, OWCH MINE, ILCHI, ACOT.

Ask the members of the other group to unscramble the following anagrams: TECKAJ, STEV, ASTEREW, OLACK, ZELBAR, ACOT.

For the first group, the correct answers are *pizza, spaghetti, chop suey, chow mein, chili*, and a sixth item. The correct answers for the second group are *jacket, vest, sweater, cloak, blazer*, and a sixth item. The sixth item in each group may be either *taco* or *coat*.

Did your volunteers show a tendency to choose one or the other answer, depending on the preceding list with which they were primed?

prime and the target, and the relative strengths of each connection. This view holds that increasing the number of intervening links tends to decrease the likelihood of the priming effect. But increasing the strength of each link between the prime and its target tends to increase the likelihood of the priming effect. This model has been well supported (e.g., McNamara, 1992). Furthermore, the occurrence of priming through spreading activation is taken by most psychologists as support for a network model of knowledge representation in memory processes. In particular, the notions of priming effects achieved by spreading activation within a network model have led to the emergence of a newer model. This model is called a *connectionist model of knowledge representation* and will be considered in more detail in the next section.

✓ CONCEPT CHECK

1. What is procedural knowledge?
2. What are the different kinds of nondeclarative knowledge?
3. What are two types of priming?

Integrative Models for Representing Declarative and Nondeclarative Knowledge

So far, we have considered models for the representation of either declarative or procedural knowledge. Next, we explore some models that attempt to explain both. The first model is the ACT-R model, which is based on semantic networks and production systems. Then we look at findings that are using the human brain, rather than computers, as a model. One such theory we will consider in detail: the connectionist model.

Last, we will discuss the question of whether psychologists should try to find models that explain all domains of knowledge representation (e.g., declarative *and* procedural knowledge), or whether it makes more sense to develop models that specialize in a particular domain.

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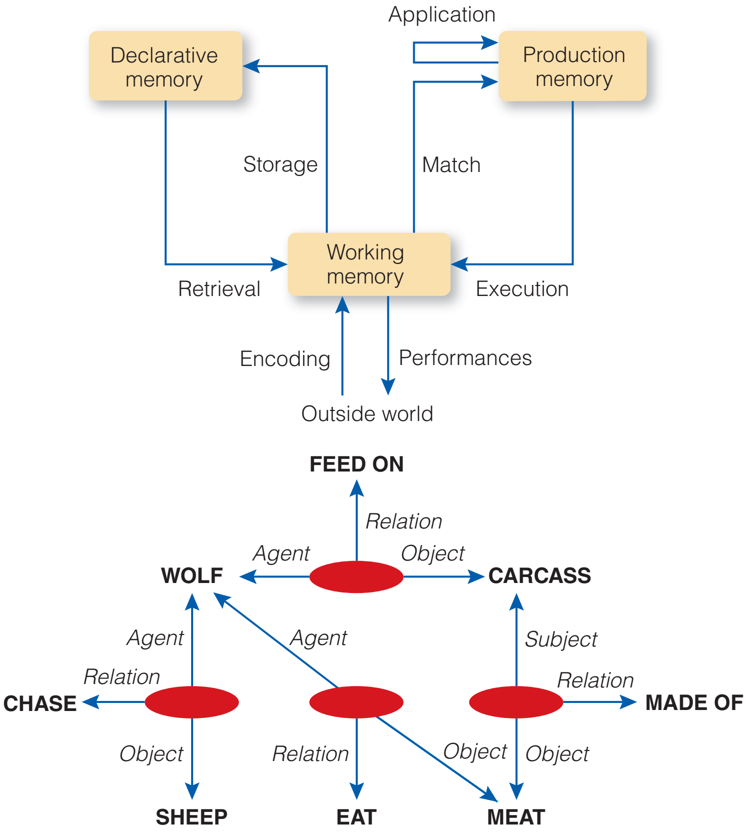
Combining Representations: ACT-R

An excellent example of a theory that combines forms of mental representation is the **ACT** (adaptive control of thought) model of knowledge representation and information processing (Borst & Anderson, 2015; Anderson, 1976, 1993; Anderson et al., 2004). In his ACT model, John Anderson synthesized some of the features of serial information-processing models and some of the features of semantic-network models. In ACT, procedural knowledge is represented in the form of production systems. Declarative knowledge is represented in the form of propositional networks. Anderson (1985) defined a proposition as being the smallest unit of knowledge that can be judged to be either true or false. Recall from Chapter 7 that propositions describe abstract relationships among elements. For example, "Bobby likes cheese sticks" is a proposition, but neither "Bobby" nor "cheese sticks" is a proposition. ACT is an evolved form of earlier models (Anderson, 1972; Anderson & Bower, 1973).

Anderson intended his model to be so broad in scope that it would offer an overarching theory regarding the entire architecture of cognition. In Anderson's view, individual cognitive processes such as memory, language comprehension, problem solving, and reasoning are merely variations on a central theme. They all reflect an underlying system of cognition. The most recent version of ACT, the **ACT-R** (where the *R* stands for *rational*), is a model of information processing that integrates a network representation for declarative knowledge and a production system representation for procedural knowledge (Anderson, 1983). Figure 8.7 ■ illustrates the ACT-R model and propositional networks in more detail.

In the ACT-R, networks include images of objects and corresponding spatial configurations and relationships. They also include temporal information, such as relationships



■ **Figure 8.7 Components of the ACT-R Model and a Propositional Network.** (a) John Anderson's most recent version of ACT-R includes declarative knowledge ("declarative memory"), procedural knowledge ("procedural memory"), and working memory (the activated knowledge available for cognitive processing, which has a limited capacity). (b) The diagram shows a propositional network representing the facts that wolves feed on carcasses, eat meat, and chase sheep. The network can be extended arbitrarily to represent more information.

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involving the sequencing of actions, events, or even the order in which items appear. Anderson referred to the temporal information as "temporal strings." He noted that they contain information about the relative time sequence. Examples would be before/after, first/second/third, and yesterday/tomorrow. These relative time sequences can be compared with absolute time referents, such as 2 P.M., September 4, 2015. The model is under constant revision and currently includes information about statistical regularities in the environment (Anderson, 1991, 1996; Weaver, 2008). It is also used to examine learning processes that are reflected in the cortex (Anderson et al., 2004; Borst & Anderson, 2015).

Declarative Knowledge within ACT-R

Anderson's declarative network model, like many other network models (e.g., Collins & Loftus, 1975), contains a mechanism by which information can be retrieved as well as a structure for storing information. Recall that within a semantic network, concepts are stored at various nodes within the network. According to Anderson's model (and various other network models), the nodes can be either inactive or active at a given time. An active node is one that is, in a sense, "turned on." A node can be turned on—activated—directly by external stimuli, such as sensations, or it can be activated by internal stimuli, such as memories or thought processes. Also, it can be activated indirectly, by the activity of one or more neighboring nodes.

Given each node's receptivity to stimulation from neighboring nodes, there is **spreading activation** within the network from one node to another. But the amount of information (number of nodes) that can be activated at any one time has limits (Danker, Gunn, & Anderson et al., 2008; Shastri, 2003). Of course, as more nodes are activated and the spread of activation reaches greater distances from the initial source of the activation, the activation weakens. Therefore, the nodes closely related to the original node have a great deal of activation. However, nodes that are more remotely related are activated to a lesser degree. For instance, when the node for *mouse* is activated, the node for *cat* also is strongly activated. At the same time, the node for *deer* is activated (because a deer is an animal as well), but to a much lesser degree. Spreading activation exists even in infants. In babies, therefore, memories do not exist as isolated "islands" but rather are incorporated into an associative network (Barr et al., 2014).

The ACT-R also suggests means by which the network changes as a result of activation. For one thing, the more often particular links between nodes are used, the stronger the links become. In a complementary fashion, activation is likely to spread along the routes of frequently traveled connections. It is less likely to spread along infrequently used connections between nodes.

Consider an analogy. Imagine a complex set of water pipes interlinking various locations. When the water is turned on at one location, the water starts moving through various pipes. It is showing a sort of spreading activation. At various interconnections, a valve is either open or closed. It thus either permits the flow to continue through or diverts the flow (the activation) to other connections.

To carry the analogy a bit further, processes such as attention can influence the degree of activation throughout the system. Consider the water system again. The higher the water pressure in the system, the farther along the water will spread through the system of pipes. To relate this metaphor back to spreading activation, consider what happens when we are thinking about an issue and various associations seem to come to mind regarding that issue (e.g., you think about tomorrow's dinner and that you have to make a shopping list, and then it occurs to you that you long promised to invite your parents for dinner, and so on). We are experiencing the spread of activation along the nodes that represent our knowledge of various aspects of the problem and, possibly, its solution.

To help explain some aspects of spreading activation, picture the pipes as being more flexible than normal pipes. These pipes gradually can expand or contract; it all depends on how frequently they are used. The pipes along routes that are traveled frequently may expand to enhance the ease and speed of travel along those routes. The pipes along routes that are seldom traveled gradually may contract. Similarly, in spreading activation, connections that frequently are used are strengthened. Connections that are seldom used are weakened. Thus, within semantic networks, declarative knowledge may be learned and maintained through the strengthening of connections as a result of frequent use. The theory of spreading activation has been applied to a number of other cognitive concepts. These concepts include social cognition and bilingualism (Dixon & Maddox, 2005; Green, 1998).

Procedural Knowledge within ACT-R

How does Anderson explain the acquisition of procedural knowledge? Such knowledge is represented in production systems rather than in semantic networks. Knowledge representation of procedural skills occurs in three stages: cognitive, associative, and autonomous (Anderson, 1980). See Table 8.2 ■ for examples of each of these three stages.

Our progress through these stages is called proceduralization (Anderson et al., 2004). *Proceduralization* is the overall process by which we transform slow, explicit information about procedures ("knowing that") into speedy, implicit, implementations of procedures ("knowing how"). (Recall the discussion of *automatization* in Chapter 4. This is a term used by other cognitive psychologists to describe essentially the same process as proceduralization.) One means by which we make this transformation is through composition. During this stage, we construct a single production rule that effectively embraces two or more production rules. It thus streamlines the number of rules required for executing the procedure. For example, consider what happens when we learn to drive a standard shift car. We may compose a single procedure for what were two separate procedures. One was for pressing down on the clutch. The other was for applying the brakes when we reach a stop sign. These multiple processes are combined together into the single procedure of driving.

Another aspect of proceduralization is "production tuning." It involves the two complementary processes of generalization and discrimination. We learn to generalize existing rules to apply them to new conditions. For example, we can generalize our use of the clutch, the brakes, and the accelerator to a variety of standard shift cars.

Table 8.2 Three Stages of Acquisition of Procedural Knowledge Using the Example of Learning to Drive a Standard-Shift Car

Stage		Example
Cognitive stage	We think about explicit rules for implementing the procedure.	When learning how to drive a car with standard shift, we must explicitly think about each rule for stepping on the clutch pedal, the gas pedal, or the brake pedal. Simultaneously, we also try to think about when and how to shift gears.
Associative stage	We consciously practice using the explicit rules extensively, usually in a highly consistent manner.	We carefully and repeatedly practice following the rules in a consistent manner. We gradually become more familiar with the rules. We learn when to follow which rules and when to implement which procedures.
Autonomous stage	We use these rules automatically and implicitly without thinking about them. We show a high degree of integration and coordination, as well as speed and accuracy.	We have integrated all the various rules into a single, coordinated series of actions. We no longer need to think about what steps to take to shift gears. We can concentrate instead on listening to our favorite radio station. We simultaneously can think about going to our destination, avoiding accidents, stopping for pedestrians, and so on.

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Finally, we learn to discriminate new criteria for meeting the conditions we face. For example, what happens after we have mastered driving a particular standard shift car? If we drive a car with a different number of gears or with different positions for the reverse gear, we must discriminate the relevant information about the new gear positions from the irrelevant information about the old gear positions. Taatgen and Lee (2003) demonstrated that the learning of even extremely complex tasks—for instance, air traffic controlling—can be described through these three processes.

Thus far, the models of knowledge representation presented in this chapter have been based largely on computer models of human intelligence. As the foregoing discussion shows, information processing theories based on computer simulations of human cognitive processes have greatly advanced our understanding of human knowledge representation and information processing.

An alternative approach to understanding knowledge representation in humans has been to study the human brain itself. Much of the research in psychobiology has offered evidence that many operations of the human brain do not seem to process information step by step, bit by bit. Instead, the human brain seems to engage in multiple processes simultaneously. It acts on myriad bits of knowledge all at once. Such models do not necessarily contradict step-by-step models. First, people seem likely to use both serial and parallel processing. Second, different kinds of processes may be occurring at different levels. Thus, our brains may be processing multiple pieces of information simultaneously. They combine into each of the steps of which we are aware when we process information step by step.

Parallel Processing: The Connectionist Model

Computer-inspired information-processing theories assume that humans, like computers, process information serially. That is, information is processed one step after another. Some aspects of human cognition may be explained in terms of serial processing, but psychobiological findings and other cognitive research seem to indicate other aspects of human cognition. These aspects involve **parallel processing**, in which multiple operations go on all at once. We have seen how the information processing of a computer has served as a metaphor for many models of cognition. Similarly, our increasing understanding of how the human brain processes information also serves as a metaphor for many of the recent models of knowledge representation in humans.

The human brain seems to handle many operations and to process information from many sources simultaneously—in parallel. In fact, it seems necessary that we are able to process information in parallel: A computer responds to an input within nanoseconds (millionths of a second), but an individual neuron may take up to 3 milliseconds to fire in response to a stimulus. Consequently, serial processing in the human brain would be far too slow to manage the amount of information the brain handles. For example, most of us can recognize a complex visual stimulus within about 300 milliseconds. If we processed the stimulus serially, only a few hundred neurons would have had time to respond, which is not enough for the perception of a complex stimulus. Therefore, the distribution of parallel processes better explains the speed and accuracy of human information processing.

As a result of these considerations, many contemporary models of knowledge representation emphasize the importance of parallel processing in human cognition. Furthermore, some computers have been made to simulate parallel processing, such as through so-called neural networks of interlinked computer processors.

At present, many cognitive psychologists are exploring the limits of parallel processing models. According to **parallel distributed processing (PDP) models** or **connectionist models**, we handle very large numbers of cognitive operations at once through a network distributed across incalculable numbers of locations in the brain (McClelland & Rogers, 2003; McClelland, Rumelhart, & the PDP Research Group, 1986; Rogers & McClelland, 2014).

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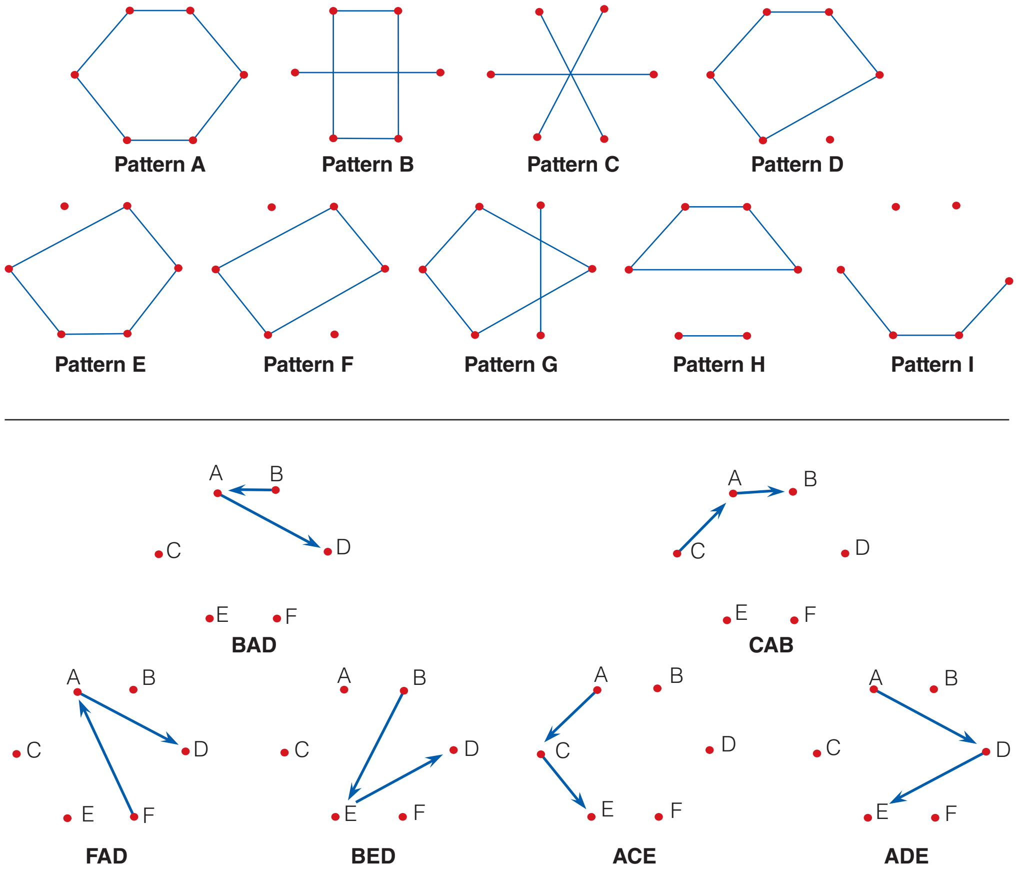
How the PDP Model Works

The mental structure within which parallel processing is believed to occur is a network. In connectionist networks, all forms of knowledge are represented within the network structure. Recall that the fundamental element of the network is the node. Each node is connected to many other nodes. These interconnected patterns of nodes enable the individual to organize meaningfully the knowledge contained in the connections among the various nodes. In many network models, each node represents a concept.

The network of the PDP model is different in key respects from the semantic network described earlier. In the PDP model, the network is made up of neuron-like units (McClelland & Rumelhart, 1981, 1985; Rogers & McClelland, 2014; Rumelhart & McClelland, 1982) They do not, in and of themselves, actually represent concepts, propositions, or any other type of information. Thus, the pattern of connections represents the knowledge, not the specific units. The same idea governs our use of language. Individual letters (or sounds) of a word are relatively uninformative, but the pattern of letters (or sounds) is highly informative. Similarly, no single unit is very informative, but the pattern of interconnections among units is highly informative. Figure 8.8 ■ illustrates how just six units (dots) may be used to generate many more than six patterns of connections between the dots.

The PDP model demonstrates another way in which a brain-inspired model differs from a computer-inspired one. Differing cognitive processes are handled by differing



■ **Figure 8.8** **Knowledge Represented by Patterns of Connections.** Each individual unit (dot) is relatively uninformative, but when the units are connected into various patterns, each pattern may be highly informative, as illustrated in the patterns at the top of this figure. Similarly, individual letters are relatively uninformative, but patterns of letters may be highly informative. Using just three-letter combinations, we can generate many different patterns, such as CAB, BED, and other patterns shown in the bottom of this figure.

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patterns of activation, rather than as a result of a different set of instructions from a computer's central processing unit. In the brain, at any one time, a given neuron may be inactive, excitatory, or inhibitory.

- *Inactive* neurons are not stimulated beyond their threshold of excitation. They do not release any neurotransmitters into the synapse (the interneuronal gap).
- *Excitatory* neurons release neurotransmitters that stimulate receptive neurons at the synapse. They increase the likelihood that the receiving neurons will reach their threshold of excitation.
- *Inhibitory* neurons release neurotransmitters that inhibit receptive neurons. They reduce the likelihood that the receiving neurons will reach their threshold of excitation.

Furthermore, although the action potential of a neuron is all or none, the amounts of neurotransmitters and neuromodulators released may vary. (Neuromodulators are chemicals that can either increase or inhibit neural activation.) The frequency of firing also may vary. This variation affects the degree of excitation or inhibition of other neurons at the synapse.

Similarly, in the PDP model, individual units may be inactive, or they may send excitatory or inhibitory signals to other units. That is not to say that the PDP model actually indicates specific neural pathways for knowledge representation. We are still a long way from having more than a faint glimmer of knowing how to map specific neural information. Rather, the PDP model uses the physiological processes of the brain as a metaphor for understanding cognition. According to the PDP model, connections between units can possess varying degrees of potential excitation or inhibition. These differences can occur even when the connections are currently inactive. The more often a particular connection is activated, the greater is the strength of the connection, whether the connection is excitatory or inhibitory.

According to the PDP model, whenever we use knowledge, we change our representation of it. Thus, knowledge representation is not really a final product. Rather, it is a process or even a potential process. What is stored is not a particular pattern of connections. It is a pattern of potential excitatory or inhibitory connection strengths. The brain uses this pattern to recreate other patterns when stimulated to do so.

When we receive new information, the activation from that information either strengthens or weakens the connections between units. The new information may come from environmental stimuli, from memory, or from cognitive processes. The ability to create new information by drawing inferences and making generalizations allows for almost infinite versatility in knowledge representation and manipulation.

This versatility is what makes humans—unlike computers—able to accommodate incomplete and distorted information. Information that is distorted or incomplete is considered to be *degraded*. According to the PDP model, human minds are flexible. They do not require that all aspects of a pattern precisely match to activate a pattern. Thus, when enough distinctive (but not all) aspects of a particular pattern have been activated by other attributes in the description, we can recreate the correct pattern even though some information is degraded. This cognitive flexibility also greatly enhances our ability to learn new information.

By using the PDP model, cognitive psychologists attempt to explain various general characteristics of human cognition. These characteristics include our ability to respond flexibly, dynamically, rapidly, and relatively accurately, even when we are given only partial or degraded information. In addition, cognitive psychologists attempt to use the model to explain specific cognitive processes. Examples of such processes include perception, reasoning, reading, language comprehension, priming, and the Stroop effect (see Chapter 4), as well as other memory processes (Kaplan et al., 2007; Laszlo & Plaut, 2012; Rogers & McClelland, 2008).

An example of the efforts to apply PDP models to specific cognitive processes can be seen through the exploration of dyslexia, or reading disability. A specific PDP model for the description of how we read was developed. This model involves pathways for both phonological and semantic representations (Plaut et al., 1996). Computer simulations with this model have been able to mimic normal reading. When one of these two pathways is damaged, these simulations are able to imitate the behavioral manifestations of dyslexia (Welbourne & Ralph, 2007). These simulations help researchers understand what processes are malfunctioning in people with reading disabilities.

Connectionist models of knowledge representation explain many phenomena of knowledge representation and processing, such as perception and memory. These processes may be learned gradually by our storing knowledge through the strengthening of patterns of network connections. But connectionist models are not flawless.

Criticisms of the Connectionist Models

One general criticism is that connectionist networks neglect properties that neural systems have or that they propose properties that neural networks do not have. Furthermore, critics ask why any model should be more credible than another for explaining cognitive mechanisms just because it resembles the structure of the brain (Thomas & McClelland, 2008).

Many aspects of the connectionist models are not yet well defined. For example, a connectionist model is less effective in explaining how people can remember a single event (Schacter, 1989). How do we suddenly construct a whole new interconnected pattern for representing what we know about a memorable event, such as graduation day?

Similarly, connectionist models do not satisfactorily explain how we often quickly can unlearn established patterns of connections when we are presented with contradictory information (Ratcliff, 1990; Treadway et al., 1992). Consider the following examples:

1. Suppose that you are told that the criteria for classifying parts of plants as fruits are that they must have seeds, pulp, and skin.
2. You also are told that whether they are sweeter than other plant parts is not important.
3. Now you are given the task of sorting various photos of plant parts into groups that are or are not fruits.
4. What happens? You will sort tomatoes and pumpkins with apples and other fruits, even if you did not previously consider them to be fruits.

These shortcomings of connectionist systems can be bypassed. It may be that the brain has two learning systems (McClelland, McNaughton, & O'Reilly, 1995). One system corresponds to the connectionist model in resisting change and in being relatively permanent. The complementary system handles rapid acquisition of new information. It holds the information for a short time. It then integrates the newer information with information in the connectionist system. Evidence from neuropsychology and connectionist network modeling seem to corroborate this account (McClelland, McNaughton, & O'Reilly, 1995). Thus, the connectionist system is spared. But we still need a satisfactory account of the other learning system.

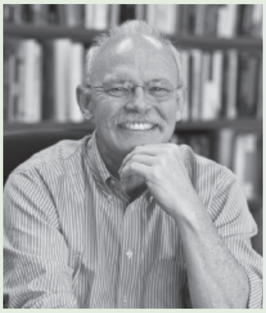
The preceding models of knowledge representation and information processing clearly have profited from technological advances in computer science, brain imaging, and the neuropsychological study of the human brain in action. These are techniques that few would have predicted to have been so promising 40 years ago. Thus, it would be foolish to predict that specific avenues of research will lead us in particular directions. Nonetheless, particular avenues of research do hold promise. For example, using powerful computers,

in the lab of **JAMES L. McCLELLAND**

Neural Network Model

In my laboratory, we attempt to understand the implications of the idea that human cognitive processes arise from the interactions of neurons in the brain. We develop computational models that directly carry out some human cognitive task using simple, neuronlike processing units. We believe that the properties of the underlying hardware have important implications for the nature and organization of cognitive processes in the brain.

An important case in point is the process of assigning the past tense to a word in English. Consider the formation of the past tense of *like, take*, and *gleat*. (*Gleat* is not a word in English, but it might be. For example, we might coin the word *gleat* to refer to the act of saluting in a particular way.) In any case, most people agree that the past tense of *like* is *liked;* the past tense of *take* is *took;* and the past tense of *gleat* should be *gleated*.


James L. McClelland

Courtesy of the author

Before the advent of neural network models, everyone in the field assumed that to form the past tense of a novel verb like *gleat*, one would need to use a rule (e.g., to form the past tense of a word, add [e]d).

Also, developmental psychologists observed that young children occasionally made interesting errors like saying “taked” instead of “took,” and they interpreted this as indicating that the children were (over)applying the rule to form past tense. They also assumed that to produce “took,” a child would need to memorize this particular item. For familiar and regular words such as *like*, either the rule or the lookup mechanism might be used.

In the brain, a single mechanism might be used to produce the past tenses of both regular and exceptional items. To explore this possibility, David Rumelhart and I created a simple neural network model. The model takes as its input a pattern of activity over a set of neuron-like units used to represent the present tense form of a word. On its output, it produces a pattern of activity over another set of units representing the past tense form of the word. As an approximation, you can think of the units as standing for features of the word, such as “begins with *t*,” “vowel is *ay*,” or “ends with *k*” so the verb *take* would be represented by turning these three units on. The network operates by propagating activation from the input units to the output units. What determines whether a unit will be active is the pattern of incoming activation to each unit. Input units are connected to output units by modifiable connections that vary in strength and can be either positive or negative; these connections are modeled after the synaptic connections between neurons that modulate the effect of a signal coming from a sending neuron on the receiving neuron on the other side of the connection. If the overall input to a neuron from other neurons is positive, it tends to turn on; if it is negative, it tends to turn off.

We trained this network with pairs of items representing the present and past tenses of familiar words. Training occurs by modifying the strengths of the connections between the input and output units so that the input pattern, say for *take,* will activate the output pattern for its past tense *took*. After we trained it with the 10 most frequent words (most of which are exceptions), the network could produce the past tenses of these words, but it did not know how to deal with other words. We then trained it with the 10 frequent words plus 400 more words, most of which were regular, and we found that early in training, it tended to overregularize most of the exceptions (e.g., it said “taked” instead of “took”), even for those words that it had previously produced correctly. After more training, it recovered its ability to produce exceptions correctly, while still producing regular past tenses for words such as *like* and for many novel items such as *gleat*. Thus, the model accounted for the developmental pattern in which children first deal correctly with exceptions, then learn how to deal with regular words and novel words and overregularize exceptions, and then later still deal correctly with regular words, novel words, and exceptions.

Our model illustrates that in a neural network, it is not necessary to have separate mechanisms to deal with rules and exceptions. In fact, it is not even necessary to have explicit rules or lists of exceptions to them. Instead, the knowledge can be in the connections among the units in the network, learned by a simple connection adjustment procedure. This conclusion remains controversial but continues to gain ground. Other work in my lab and in other labs extends these ideas to reading, other aspects of language including grammar, and to semantics, where there are many things like penguins and elephants that have exceptional properties. More recently, we have been exploring how these ideas can help explain why it takes a long time to acquire mathematical abilities.

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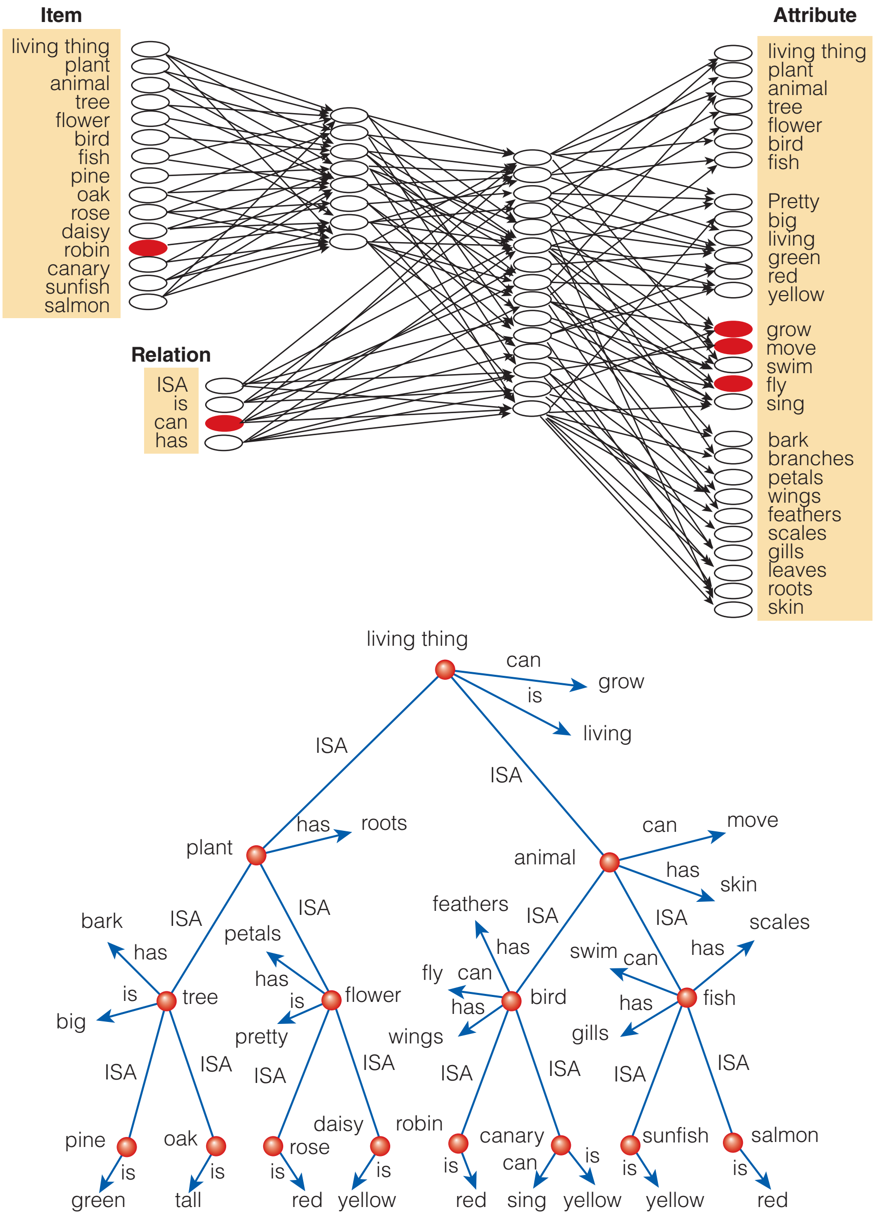
researchers are attempting to create parallel processing models via neural networks. Increasingly sophisticated techniques for studying the brain offer intriguing possibilities for research. Case studies, naturalistic studies, and traditional laboratory experiments in the field of cognitive psychology also offer rich opportunities for further exploration. Some researchers are trying to explore highly specific cognitive processes, such as auditory processing of speech sounds. Others are trying to investigate fundamental processes that underlie all aspects of cognition. Which type of research is more valuable?

Comparing Connectionist with Network Representations

How do connectionist models compare with network models? Figure 8.9 ■ shows the concept of a robin as represented by both a network model and a connectionist model.


Item
living thing
plant
animal
tree
flower
bird
fish
pine
oak
rose
daisy
robin
canary
sunfish
salmon
Relation
ISA
is
can
has
Attribute
living thing
plant
animal
tree
flower
bird
fish
Pretty
big
living
green
red
yellow
grow
move
swim
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green
tall
red
yellow
red
sing
yellow
yellow
red

■ Figure 8.9 Network and Connectionist Representations. Network and connectionist representations of concepts relating to birds. The network representation on the left illustrates how knowledge is built up like a tree with more superordinate concepts at the top. The connectionist representation on the right has three layers: item, relation, and attribute. Each unit in the relation layer restricts the information that can be retrieved—a "can" relation activates different attributes than a "has" relation, for example. Thus, the "robin can" constellation represents a situation in which one is presented with a bird and asked what that bird can do.

Source: Based on J. L. McClelland, "Connectionist Model of Memory," in E. Tulving & F. I. M. Craik (eds.), *The Oxford Handbook of Memory,* pp. 583–596. Copyright © 2000 Oxford University Press.

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In the network representation, the nodes represent concepts. When we learn, we add new entries to the hierarchy in the network so that the hierarchy gets more elaborate. An individual builds up a knowledge base about a robin over time as more and more information is acquired about robins. Note that information about robins is embedded in a general network representation that goes beyond just robins. One's understanding of robins partly depends on the relationship of the robin to other birds and even other kinds of living things. Indeed, perhaps the most fundamental feature of the robin is that it is a living thing. So this information is represented at the top to show that it is an extremely general characteristic of a robin. Living things are living and can grow, so this information is also represented at a general level. As one moves down the network, information gets increasingly specific. For example, we learn that a robin is a bird and that it is partly red.

In contrast, the connectionist network represents patterns of activation. When we learn, we strengthen the connection between the nodes (rather than merely adding new nodes, as in the network representation). Here, too, the network shows knowledge that goes beyond just birds. But the knowledge is in the connections rather than in the nodes. Through activation of certain connections, knowledge about a robin is built up. A strong connection is one that is activated many times, whereas a weak connection is activated only on rare occasions.

How Domain General or Domain Specific Is Cognition?

Should cognitive psychologists try to find a set of mental processes that is common across all domains of knowledge representation and processing? Or should they study mental processes specific to a particular domain? In early AI research, investigators believed that the ideal was to write programs that were as domain general as possible. Although none of the programs truly worked in all domains, they were a good start. Similarly, in the broader field of cognitive psychology, the trend in the 1960s through the mid-1970s was to strive for domain general understandings of cognitive processes (Miller, Galanter, & Pribram, 1960; Simon, 1976).

Starting in the late 1970s, the balance shifted toward domain specificity. In part, this was because of striking demonstrations regarding the role of specific knowledge in chess playing (Chase & Simon, 1973; De Groot, 1965; see Chapter 11). A key book, *The Modularity of Mind*, presented an argument for extreme domain specificity (Fodor, 1983). In this view, the mind is **modular**, divided into discrete modules that operate more or less independently of each other. According to Fodor, each independently functioning module can process only one kind of input, such as language (e.g., words), visual percepts (e.g., faces), and so on.

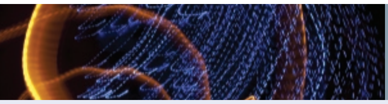
Further evidence for the domain specificity of face recognition can be observed in studies employing functional magnetic resonance imaging (fMRI) methods. In one study, it was observed that when subjects viewed faces and houses, different brain areas were active. It thus appears that there are both specialized brain and cognitive processes for face recognition. This finding is taken to suggest that there is domain specificity for facial recognition (Yovel & Kanwisher, 2004). Studies have found domain specificity for other things like scenes and bodies as well (Downing et al., 2006).

Fodor (1983) asserted the modularity (distinct origins) of lower level processes, such as the basic perceptual processes involved in lexical access. However, the application of modularity has been extended to higher intellectual processes as well (Gardner, 1983). Also, Fodor's book emphasized the modularity of specific cognitive functions, such as lexical access to word meanings, as distinct from word meanings derived from context. These functions primarily have been observed in cognitive experiments. Issues of modularity, however, also have been important in neuropsychological research. For example, discrete pathological conditions are associated with discrete cognitive deficits.

Recently, there has been more of an attempt to integrate domain-specific and domain-general perspectives in our thinking about knowledge representation and processing. In the chapters that follow, you may wish to reflect on whether the processes and forms of knowledge representation are primarily domain general or primarily domain specific.

CONCEPT CHECK

1. What is the ACT-R model?
2. How is procedural knowledge represented in the ACT-R model?
3. What is parallel processing?
4. How does a connectionist network represent knowledge?
5. What is domain specificity?



Key Themes

This chapter brings out several of the key themes described in Chapter 1.

Rationalism versus empiricism. How do we assign meaning to concepts? The featural view is largely a rationalistic one. Concepts have sets of features that are largely a priori and that are the same from one person to another. The underlying notion is that one could understand a concept by a detailed dictionary definition, pretty much without reference to people's experience. The prototype-, exemplar-, and theory-based views are much more empirically based. They assign a major role to experience. For example, theories may change with experience. The theory of a concept such as a "dog" that a 3-year-old child has may be quite different from that of a 10-year-old child.

Validity of causal inference versus ecological validity. Early research on concepts, such as that of Bruner, Goodnow, and Austin, used abstract concepts, such as geometric forms that could be of different colors, shapes, and sizes. But in her work, Eleanor Rosch called this approach into question. Rosch argued that natural concepts show few of the characteristics of artificial ones. Studying artificial concepts, therefore, might yield information that applied to those concepts but not necessarily to real-world ones. Modern researchers tend to study real-world concepts more than artificial ones.

Applied versus basic research. Basic research on concepts has generated a great deal of applied research. For example, market researchers are interested in people's conceptualizations of commercial products. They use empirical and statistical techniques to understand how products are conceived. Often, then, advertising serves to reposition the products in customers' minds. For example, a car that is viewed as in the category of "economy cars" may be moved, through advertising, to a more "upscale car" category.

SUMMARY

1. **How are representations of words and symbols organized in the mind?** The fundamental unit of symbolic knowledge is the concept. Concepts may be organized into categories, which may include other categories. They may be organized into schemas, which may include other schemas. They also may vary in application and in abstractness.

   Finally, they may include information about relationships among concepts, attributes, contexts, and general knowledge and information about causal relationships. There are different general theories of categorization. They include feature-based definitional categories, prototype-based categories, and exemplar-based approaches. One of the forms for schemas is the script. An alternative model for knowledge organization is a semantic network, involving a web of labeled relations between conceptual nodes. An early network model, based on the notion of cognitive economy, was strictly hierarchical. But subsequent models have tended to emphasize the frequency with which particular associations are used.
2. **How do we represent other forms of knowledge in the mind?** Many cognitive psychologists have developed models for procedural knowledge. These are based on computer simulations of such representations. An example of such a model is the production system.
3. **How does declarative knowledge interact with procedural knowledge?** An important model in cognitive psychology is ACT, as well as its updated revision, ACT-R. It represents both procedural knowledge in the form of production systems and declarative knowledge in the form of a semantic network. In each of these models, the metaphor for understanding both knowledge representation and information processing is based on the way in which a computer processes information. For example, these models underscore the serial processing of information.

   Research on how the human brain processes information has shown that brains, unlike computers, use parallel processing of information. In addition, it appears that much of information processing is not localized only to particular areas of the brain. Instead, it is distributed across various regions of the brain all at once. At a microscopic level of analysis, the neurons within the brain may be inactive, or they may be excited or inhibited by the actions of other neurons with which they share a synapse. Finally, studies of how the brain processes information have shown that some stimuli seem to prime a response to subsequent stimuli so that it becomes easier to process the subsequent stimuli.

   A model for human knowledge representation and information processing based on what we know about the brain is the parallel distributed processing (PDP) model. It is also called a *connectionist model*. In such models, it is held that neuron like units may be excited or inhibited by the actions of other units, or they may be inactive. Furthermore, knowledge is represented in terms of patterns of excitation or inhibition strengths, rather than in particular units. Most PDP models also explain the priming effect by suggesting the mechanism of spreading activation.

   Many cognitive psychologists believe that the mind is at least partly modular. It has different activity centers that operate fairly independently of each other. Other cognitive psychologists believe, however, that human cognition is governed by many fundamental operations. According to this view, specific cognitive functions are merely variations on a theme. In all likelihood, cognition involves some modular, domain-specific processes and some fundamental, domain-general processes.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Define *declarative knowledge* and *procedural knowledge*, and give examples of each.
2. What is a script that you use in your daily life? How might you make it work better for you?
3. Describe some of the attributes of schemas, and compare and contrast two of the schema models mentioned in this chapter.
4. In your opinion, why have many of the models for knowledge representation come from people with a strong interest in AI?
5. What are some advantages and disadvantages of hierarchical models of knowledge representation?
6. How would you design an experiment to test whether a particular cognitive task was better explained in terms of modular components, or in terms of some fundamental underlying domain general processes?
7. What are some practical examples of the forms of nondeclarative knowledge in Squire's model? (For ideas on conditioning, see Chapter 1; for ideas on habituation or on priming, see Chapter 4.)
8. How might you use semantic priming to enhance the likelihood that a person will think of something you would like the person to think of (e.g., your birthday, a restaurant to visit, or a movie to view)?

KEY TERMS

ACT, p. 316
ACT-R, p. 316
artifact categories, p. 295
basic level, p. 296
category, p. 294
characteristic features, p. 298
concept, p. 294
connectionist models, p. 319
converging operations, p. 294
core, p. 300
defining features, p. 296
exemplars, p. 299
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parallel distributed processing (PDP) models, p. 319
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production, p. 312
production system, p. 313
prototype p. 298
prototype theory, p. 298
schemas, p. 307
script, p. 309
serial processing, p. 312
spreading activation, p. 317
theory-based view of meaning, p. 301

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 45—Absolute Identification
Lab 46—Implicit Learning
Lab 47—Prototypes

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Language

9

CHAPTER OUTLINE

What Is Language?
  - Properties of Language
  - The Basic Components of Words and Sentences

Language Comprehension
  - Understanding Words
    - The View of Speech Perception as Ordinary
    - The View of Speech Perception as Special
  - Understanding Meaning: Semantics
  - Understanding Sentences: Syntax
    - Syntactical Priming
    - Speech Errors
    - Analyzing Sentences: Phrase-Structure Grammar
    - A New Approach to Syntax: Transformational Grammar
    - Relationships between Syntactical and Lexical Structures

Reading
  - Perceptual Issues in Reading
  - Lexical Processes in Reading
    - Fixations and Reading Speed
    - Lexical Access
  - Teaching How to Read
  - When Reading Is a Problem—Dyslexia

Understanding Conversations and Essays: Discourse
  - Comprehending Known Words: Retrieving Word Meaning from Memory
  - Comprehending Unknown Words: Deriving Word Meanings from Context
  - Comprehending Ideas: Propositional Representations
  - Comprehending Text Based on Context and Point of View
  - Representing Text in Mental Models

Key Themes

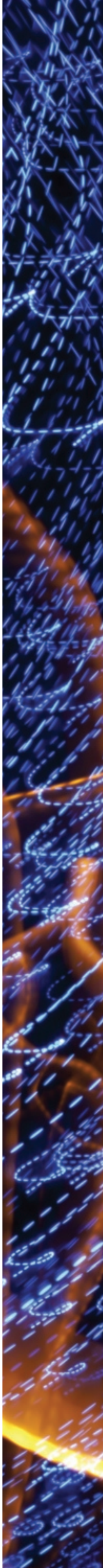
Summary

Thinking about Thinking: Analytical, Creative, and Practical Questions

Key Terms

Media Resources

■ **CogLab** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some questions we will explore in this chapter:

1. What properties characterize language?
2. What are some of the processes involved in language?
3. How do perceptual processes interact with the cognitive processes of reading?
4. How does discourse help us understand individual words?

BELIEVE IT OR NOT Do the Chinese Think about Numbers Differently Than Americans?

How languages name numbers and how they are pronounced differs widely. Even English and French have significant differences. For example, in English, the number 80 is called *eighty*, and in French it is *quatre-vingt* (literally, "four twenty," or 4 × 20).

Do those differences in language influence how our brain processes numbers and mathematics? This is what a Chinese research team set out to explore. Native Chinese speakers and Native English speakers worked on numerical tasks while being monitored by a functional magnetic resonance imaging (fMRI) machine. For simple addition tasks, different areas of the brain were activated: English speakers used processes that involved the left perisylvian cortices, whereas Chinese speakers used a visuopremotor network for the addition tasks. The results suggest that language influences the way non-language-related content is processed. It is also possible that the Chinese language's brevity for numbers (e.g., number words in Chinese generally contain fewer syllables than in English) increases working memory capacity, which in turn can result in more efficient processing (Tang et al., 2006).

In this chapter, we will explore what language is, how we process language, and how it can influence our understanding of facts and the environment.

> *I stood still, my whole attention fixed upon the motions of her fingers. Suddenly, I felt a misty consciousness as of something forgotten—a thrill of returning thought; and somehow the mystery of language was revealed to me.*
>
> *I knew then that "w-a-t-e-r" meant the wonderful cool something that was flowing over my hand. That living word awakened my soul, gave it light, joy, set it free! . . . Everything had a name, and each name gave birth to a new thought. As we returned to the house every object which I touched seemed to quiver with life. . . . I learned a great many new words that day . . . words that were to make the world blossom for me.*
>
> —Helen Keller, *Story of My Life*

Helen Keller became both blind and deaf at 19 months of age after a severe childhood illness. She was first awakened to a sentient, thought-filled, comprehensible world through her teacher, Anne Sullivan. The miracle worker held one of Helen's hands under a spigot from which a stream of water gushed over Helen's hand. All the while she spelled with a manual alphabet into Helen's other hand the mind awakening word *w-a-t-e-r*.

Language is the use of an organized means of combining words to communicate with those around us. It also makes it possible to think about things and processes we currently cannot see, hear, feel, touch, or smell. These things include ideas that may not have any tangible form. As Helen Keller demonstrated, the words we use may be written, spoken, or otherwise signed (e.g., via American Sign Language [ASL]). Even so, not all **communication**—exchange of thoughts and feelings—is through language. Communication encompasses other aspects: Nonverbal communication, such as gestures or facial expressions, can be used to embellish or to indicate. Glances serve many purposes. For example, sometimes they are deadly, other times, seductive. Communication also can include touches, such as handshakes, hits, and hugs. These are only a few of the ways we can communicate.

Psycholinguistics is the psychology of our language as it interacts with the human mind. It considers both production and comprehension of language (Gernsbacher & Kaschak, 2003a, 2003b; Wheeldon, Meyer, & Smith, 2003). Four areas of study have contributed greatly to an understanding of psycholinguistics:

- *linguistics*, the study of language structure and change
- *neurolinguistics*, the study of the relationships among the brain, cognition, and language
- *sociolinguistics*, the study of the relationship between social behavior and language (Carroll, 1986; Holmes, 2013)
- *computational linguistics* and *psycholinguistics*, the study of language via computational methods (Coleman, 2003; Clark, Fox, & Lapping, 2012; Sedivy, 2014)

This chapter first briefly describes some general properties of language. The next sections discuss the processes of language. These processes include how we understand the meanings of particular words, and how we structure words into meaningful sentences. After our exploration of general language processes, we turn to the question of how we read. And last but not least, we discuss how comprehension of larger language and text units, like essays or conversation, works. Chapter 10 describes the broader context within which we use language. This context includes the psychological and social contexts of language.

What Is Language?

Almost 7,000 languages are spoken in the world today. About 2,500 of these languages are at risk for extinction (BBC, 2014). New Guinea is the country with perhaps the most languages in the world—it has more than 850 indigenous languages, which means that on average, each language has just about 7,000 speakers. Surprisingly, even in the 21st century, some languages still have not even been "discovered" and named by scientists. A linguist who traveled to southwestern China's Yunnan province in 2006 discovered 18 languages, spoken by members of the Phula ethnic group, that never before had been defined and named (Erard, 2009). Linguists do not yet know about many more languages. Part of the reason for the Phula languages not having been discovered earlier is that speakers of the language live in mountainous areas that are hard to access. What exactly constitutes a language, and are there some things that all languages have in common?

Properties of Language

Languages can be strikingly different, but they all have some commonalities (Brown, 1965; Clark & Clark, 1977; Glucksberg & Danks, 1975). No matter what language you speak, languages are:

1. *Communicative:* Language permits us to communicate with one or more people who share our language.

2. *Arbitrarily symbolic:* Language creates an arbitrary relationship between a symbol and what it represents: an idea, a thing, a process, a relationship, or a description.
3. *Regularly structured:* Language has a structure; only particularly patterned arrangements of symbols have meaning, and different arrangements yield different meanings.
4. *Structured at multiple levels:* The structure of language can be analyzed at more than one level (e.g., in sounds, meaning units, words, and phrases).
5. *Generative, productive:* Within the limits of a linguistic structure, language users can produce novel utterances. The possibilities for creating new utterances are virtually limitless.
6. *Dynamic:* Languages constantly evolve.

Let's examine the six properties of language in more detail. The *communicative property* of language may be the most obvious feature, but it is also the most remarkable one. As an example, you can write what you are thinking and feeling so that others may read and understand your thoughts and feelings. Yet, as you may know from your own experience, the communicative property of language has occasional flaws. Despite the frustrations of miscommunications, however, for one person to be able to use language to communicate with another is impressive.

What may be more surprising is the second property of language. We communicate through our shared system of *arbitrary symbolic* reference to things, ideas, processes, relationships, and descriptions (Steedman, 2003). Words are symbols that were chosen arbitrarily to represent something else, such as a "tree," "swim," or "brilliant." The thing or concept in the real world that a word refers to is called **referent**. By consensual agreement, these combinations of letters or sounds may be meaningful to us. But the particular symbols themselves do not lead to the meaning of the word, which is why different languages use different sounds to refer to the same thing (e.g., *Baum, árbol, tree*).

Symbols are convenient because we can use them to refer to things, ideas, processes, relationships, and descriptions that currently are not present, such as the Amazon River. We even can use symbols to refer to things that never have existed, such as dragons or elves. And we can use symbols to refer to things that exist in a form that is not physically tangible, such as calculus, truth, or justice. Without arbitrary symbolic reference, we would be limited to symbols that somehow resembled the things they are symbolizing (e.g., we would need a treelike symbol to represent a tree).

Two principles underlying word meanings are the *principle of conventionality* and the *principle of contrast* (Clark, 1993, 1995; Diesendruck, 2005). The principle of conventionality simply states that meanings of words are determined by conventions—they have a meaning upon which people agree. According to the principle of contrast, different words have different meanings. Thus, when you have two different words, they represent two things that are at least slightly different. Otherwise, what would be the point of having two different words for the same thing?

The third property is the *regular structure* of language: Particular patterns of sounds and of letters form meaningful words. Random sounds and letters, however, usually do not. Furthermore, particular patterns of words form meaningful sentences, paragraphs, and discourse. Most others make no sense. Later in this chapter, we will look more closely at the structure of language.

The fourth property is that language is *structured at multiple levels*. Any meaningful utterance can be analyzed at more than one level. Let's see at what levels psycholinguists study language. They look at the following:

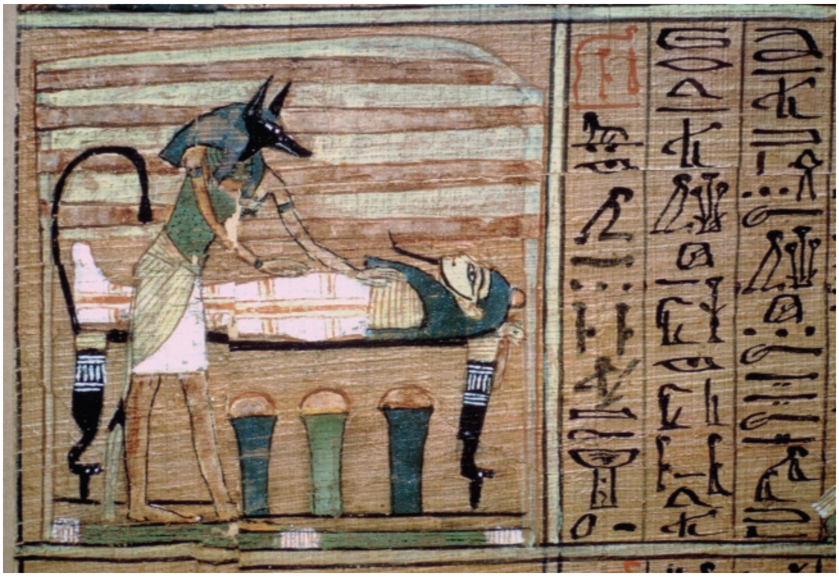
- *sounds,* such as *p* and *t*
- *words,* such as *pat, tap, pot, top, pit,* and *tip*

- *sentences,* such as “Pat said to tap the top of the pot, then tip it into the pit”
- *larger units of language,* such as this paragraph or even this book

A fifth property of language is *productivity* (sometimes termed *generativity*). In this context, *productivity* refers to our vast ability to produce language creatively. Our use of language, however, does have limitations. We have to conform to a particular structure and use a shared system of arbitrary symbols. We can use language to produce an infinite number of unique sentences and other meaningful combinations of words. Although the number of sounds (e.g., *s* as in “hiss”) used in a language may be finite, the various sounds can be combined endlessly to form new words and new sentences. Among them are many novel utterances—linguistic expressions that are brand new and never have been spoken before by anyone. Thus, language is inherently creative. None of us possibly could have heard all of the sentences we are capable of producing and that we actually produce in the course of our everyday lives. Any language appears to have the potential to express any idea in it that can be expressed in any other language. The ease, clarity, and succinctness of expression of a particular idea, however, may vary greatly from one language to the next. Thus, the creative potential of different languages appears to be roughly the same.

Finally, the productive aspect of language quite naturally leads to the *dynamic*, evolutionary nature of language. Individual language users coin words and phrases and modify language usage. The wider group of language users either accepts or rejects the modifications. Each year, recently coined words are added to the dictionary, signifying the extensive acceptance of these new words. You’re surely familiar with the word *selfie* (a photo of yourself, usually with a cell phone), which has been in use since the year 2002 (*Merriam-Webster*, 2014). A brand new word that was just added in November 2014 to the *Cambridge Dictionaries Online* is *ped-text* (which refers to a person texting on their smart phone while walking). Can you think of other newly minted words that did not exist a decade ago?

Similarly, words that are no longer used are removed from the dictionary, further contributing to the evolution of language. To imagine that language would never change is almost as incomprehensible as to imagine that people and environments would never change. For example, the modern English we speak now evolved from Middle English, and Middle English evolved from Old English.



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Signs that resemble the object they represent (i.e., their referent) are called *icons*. These pictographs are icons that were used in ancient Egyptian hieroglyphics. In contrast, most language involves the manipulation of symbols, which bear only an arbitrary relation to their referents.

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To give you an example of how English has evolved, here is a sample from the epic poem *Beowulf*, written in Old English around 900 A.D. On the right, you can see a translation in modern English.

Hwæt! We Gardena in geardagum, þeodcyninga, þrym gefrunon, hu ða æþelingas ellen fremedon.	Lo, praise of the prowess of people-kings of spear-armed Danes, in days long sped, we have heard, and what honor the athelings won!

And here is the beginning of the *Canterbury Tales* by Geoffrey Chaucer, written in Middle English in the 14th century:

Whan that aprill with his shoures soote	When April with his showers sweet with fruit
The droghte of March hath perced to the roote,	The drought of March has pierced unto the root
And bathed every veyne in swich licour	And bathed each vein with liquor that has power

Although we can delineate various properties of language, it is important always to keep in mind the main purpose of language: to construct a mental representation of a situation that enables us to understand the situation and communicate about it (Budwig, 1995; Radvansky & Dijkstra, 2007; Zwaan & Radvansky, 1998).

In other words, ultimately, language is primarily about use, not just about one set of properties or another. For example, it provides the basis for linguistic encoding in memory. You are able to remember things better because you can use language to help you recall or recognize them.

To conclude, many differences exist among languages. Nevertheless, they share some common properties. Among them are communication, arbitrary symbolic reference, regularity of structure, multiplicity of structure, productivity, and change. Next, we consider, in more detail how language is used. Then we observe some universal aspects of how we humans acquire our primary language.

The Basic Components of Words and Sentences

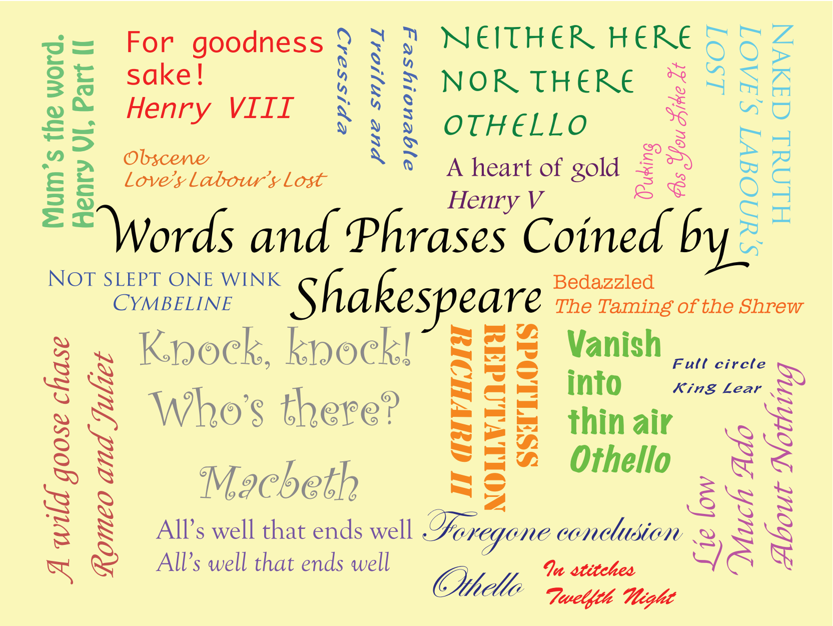
Language can be broken down into many smaller units. It is much like the analysis of molecules into basic elements by chemists. A **phoneme** is the smallest unit of speech sound that can be used to distinguish one utterance from another (i.e., to change the meaning of a word). In English, phonemes are made up of vowel or consonant sounds, like *a*, *i*, *s*, and *f*. For example, the word *sit* contains the phonemes /s/, /i/, and /t/, and by changing the phonemes we can change the meaning of sit to *sat, fat,* and *fit*. Different languages use different numbers and combinations of phonemes. North American English has about 40 phonemes, and Hawaiian has about 13 phonemes. Some African dialects have up to 60. The study of the particular phonemes of a language is called *phonemics*.

Phonetics is the study of how to produce or combine speech sounds or to represent them with written symbols (Roca, 2003). Linguists may travel to remote villages to observe, record, and analyze different languages. The study of phonetic inventories of diverse languages is one of the ways linguists gain insight into the nature of language (Hoff & Shatz, 2007; Ladefoged & Maddieson, 1996). In many cases, however, it is hard to explore a given language because many languages are dying: It is estimated that about one language dies every three months (Campbell et al., 2013). Language death occurs for a variety of reasons, including members leaving tribal areas in favor of more urban areas, genocide, globalization, and the introduction of a new language to an area (Grimes, 2010; Mufwene, 2004).

At the next level of the hierarchy after the phoneme is the **morpheme**—the smallest unit of meaning within a particular language. The word *recharge* contains two morphemes, *re-* and *charge*, in which "re" indicates a repeated action. The word *cable* consists of only one morpheme, although it is made up of two syllables—the syllables *ca* and *ble* do not have any inherent meaning.

A **lexicon** is the entire set of morphemes in a given language or in a given person's linguistic repertoire. The average adult speaker of English has a lexicon of about 80,000 morphemes (Miller & Gildea, 1987). Children in first grade in the United States have approximately 10,000 words in their vocabularies. By third grade, they have about 20,000. By fifth grade, they have reached about 40,000, or half of their eventual adult level of attainment (Anglin, 1993). By combining morphemes, most adult English speakers have a vocabulary of hundreds of thousands of words. For example, by attaching just a few morphemes to *study*, we have *student, studious, studied, studying*, and *studies*. Vocabulary is built up slowly. It develops through many diverse exposures to words and clues as to their meanings (Akhtar & Montague, 1999; Hoff & Naigles, 1999; Woodward & Markman, 1998). One of the ways in which English has expanded to embrace an increasing vocabulary is by combining existing morphemes in novel ways. Some suggest that a part of William Shakespeare's genius lay in his creation of new words by combining existing morphemes. He is alleged to have coined more than 1,700 words—8.5% of his written vocabulary—and countless expressions—including the word *countless* itself, but also other words like *inauspicious*, *pander*, and *dauntless* (Lederer, 1991).

Although we easily put together sentences when we speak, a substantial framework of rules hides behind our creation of these sentences. **Syntax** refers to the way we put words together to form sentences. It plays a major role in our understanding of language. A sentence has at least two parts. The first is a **noun phrase**, which contains at least one noun (like "man") and includes all the relevant descriptors of the noun (like "big" or "fast"). The second is a **verb phrase** (*predicate*), which contains at least one verb and


Words and Phrases Coined by Shakespeare
Mum's the word.
Henry VI, Part II
For goodness sake!
Henry VIII
Troilus and Cressida
Fashionable
NEITHER HERE NOR THERE
OTHELLO
LOVE'S LABOUR'S LOST
NAKED TRUTH
Obscene
Love's Labour's Lost
A heart of gold
Henry V
Puking
As You Like It
NOT SLEPT ONE WINK
CYMBELINE
Bedazzled
The Taming of the Shrew
Knock, knock! Who's there?
Macbeth
SPOTLESS REPUTATION
RICHARD II
Vanish into thin air
Othello
Full circle
King Lear
A wild goose chase
Romeo and Juliet
All's well that ends well
All's well that ends well
Foregone conclusion
Othello
In stitches
Twelfth Night
Lie low
Much Ado About Nothing

Courtesy of the author

Some of the new words and expressions Shakespeare created.

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whatever the verb acts on (like "runs"), if anything. The syntactical structure of language specifically is addressed later in this chapter.

CONCEPT CHECK

1. What are some important properties of language?
2. What is the difference between phonemes and morphemes?

Language Comprehension

Many processes are involved when we try to understand what somebody says. First of all, we need to perceive and recognize the words that are being said. Then we need to assign meaning to those words. In addition, we have to make sense of sentences we hear. These processes will be discussed in the next sections.

Understanding Words

Have you ever needed to communicate with someone on the cell phone, but the speech you heard was garbled because of faulty cell phone reception? If so, you will agree that speech perception is fundamental to language use in our everyday lives. Understanding speech is crucial to human communication. In this section, we investigate how we perceive speech. We also reflect on the question of whether speech is somehow special among all the various sounds we can perceive.

We are able to perceive speech with amazing rapidity. On the one hand, we can perceive as many as fifty phonemes *per second* in a language in which we are fluent (Foulke & Sticht, 1969). When confronted with nonspeech sounds, on the other hand, we can perceive less than one sound per second (Warren et al., 1969). This limitation explains why foreign languages are difficult to understand (when we hear them), and sound like they are spoken quickly. The sounds of their letters and letter combinations are different from the sounds corresponding to the same letters and letter combinations in our native language. For example, the author's Spanish sounds "American" because he tends to reinterpret Spanish sounds in terms of the American English phonetic system, rather than the Spanish one.

Another problem we face when we try to understand what somebody else is saying is that no word sounds exactly the same when it is spoken across the various speakers who say the word. Pronunciation of words varies considerably across people. People speak faster or slower, or they may pronounce sounds differently depending on where they come from. For example, one of the author's elementary school teachers pronounced *get* in a way that sounded like *git*. Speech sounds are variable, but even if a word sounds different every time we hear it, we still need to be able to figure out what word it is. What makes it even more complicated is that often we pronounce more than one sound at the same time. This is called **coarticulation**. One or more phonemes begin while other phonemes still are being produced. For example, say the words *palace* and *pool*. They both begin with a *p* sound. But can you notice a difference in the shape of your lips when you say the *p* of pool as compared with the *p* of palace? You are already preparing for the following vowel as you pronounce the *p* sound, and this affects the sound you produce. Not only do phonemes within a word overlap, but the boundaries between words in continuous speech also tend to overlap.

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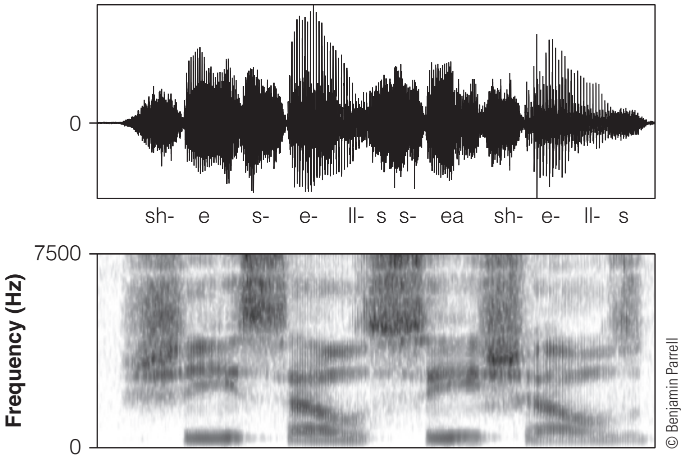

■ **Figure 9.1** **Spectrogram.** Spectrograms record physical sound patterns. In this image, you can see a record of the spoken sentence "She sells sea shells." Note that merely by looking at the pattern of the spectrogram, you cannot recognize where one word ends and the next one begins.

The process of trying to separate the continuous sound stream into distinct words is called *speech segmentation*. Figure 9.1 ■ shows a spectrogram that records physical sound patterns. As you can see, there is often no pause between words, while at the same time, there can be breaks within words. That is to say, the recording of speech sound waves poorly resembles what we hear.

This overlapping of speech sounds may seem to create additional problems for perceiving speech, but coarticulation is viewed as necessary for the effective transmission of speech information (Liberman et al., 1967). Thus, speech perception is viewed as different from other perceptual abilities because of both the linguistic nature of the information and the particular way in which information must be encoded for effective transmission.

Coarticulation can be observed in nonverbal language as well. A number of studies have examined speech production in skilled signers (i.e., people who communicate in sign language). People who are skilled signers can convey many paragraphs worth of information in less than a minute (Lupton, 1998). A great deal of coarticulation occurs in skilled use of American Sign Language (ASL; Grosvald & Corina, 2008; Jerde, Soechting, & Flanders, 2003). This coarticulation affects a number of aspects of the sign, both as it begins and as it leads into another sign. The affected aspects include hand shape, movement, and position (Yang & Sarkar, 2006).

So, how do we perceive speech with such ease? Many alternative theories of speech perception explain our facility. These theories differ mainly as to whether speech perception is viewed as special, or ordinary, with respect to other types of auditory perception.

The View of Speech Perception as Ordinary

One approach to speech perception suggests that when we perceive speech, we use the same processes as when we perceive other sounds like the crowing of a rooster. These kinds of theories emphasize either template-matching or feature-detection processes. They suggest that there are different stages of neural processing: In one stage, speech sounds are analyzed into their components. In another stage, these components are analyzed for patterns and matched to a prototype or template (Kuhl, 1991; Massaro, 1987; Stevens & Blumstein, 1981). However, feature detection or template-matching is not enough; decision-making processes are required as well. This is because the speech we perceive may differ from the speech sounds that actually reach our ears: Cognitive and contextual factors influence our perception of the sensed signal. For example, the **phonemic-restoration effect** involves integrating what we know with what we hear

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when we perceive speech (Groppe et al., 2010; Kashino, 2006; Warren, 1970; Warren & Warren, 1970).

Suppose that you were in an experiment. You are listening to a sentence having the following pattern: "It was found that the *eel was on the ______." For the final word, one of the following words is inserted: *axle, shoe, table*, or *orange*. In addition, the speaker inserts a cough instead of the initial sound where the asterisk appeared in "*eel." Virtually all participants are unaware that a consonant has been deleted. The sound they recall having heard differs according to the context. The participants recall hearing "the *wheel* was on the axle," "the *heel* was on the shoe," "the *meal* was on the table," or "the *peel* was on the orange." In essence, they restore the missing phoneme that best suits the context of the sentence.

How well do we understand words that we hear without any context? Researchers recorded speech acts by different individuals and then presented individual words without any context to their participants. Depending on whether the speaker spoke at a slow, normal, or fast speed, the isolated words were only correctly identified 68% (slow speech) to 41% of the time (fast speech; Miller & Isard, 1963).

Phonemic restoration is similar to the visual phenomenon of closure, which is based on incomplete visual information. Indeed, one main approach to auditory perception attempts to extend to various acoustic events, including speech, the Gestalt principles of visual perception (Bregman, 1990; Shahin, Bishop, & Miller, 2009). These principles include, for example, symmetry, proximity, and similarity. Thus, theories that consider speech perception as ordinary use general perceptual principles of feature-detection and Gestalt psychology. They thereby attempt to explain how listeners understand speech. Other theorists, however, view speech perception as special.

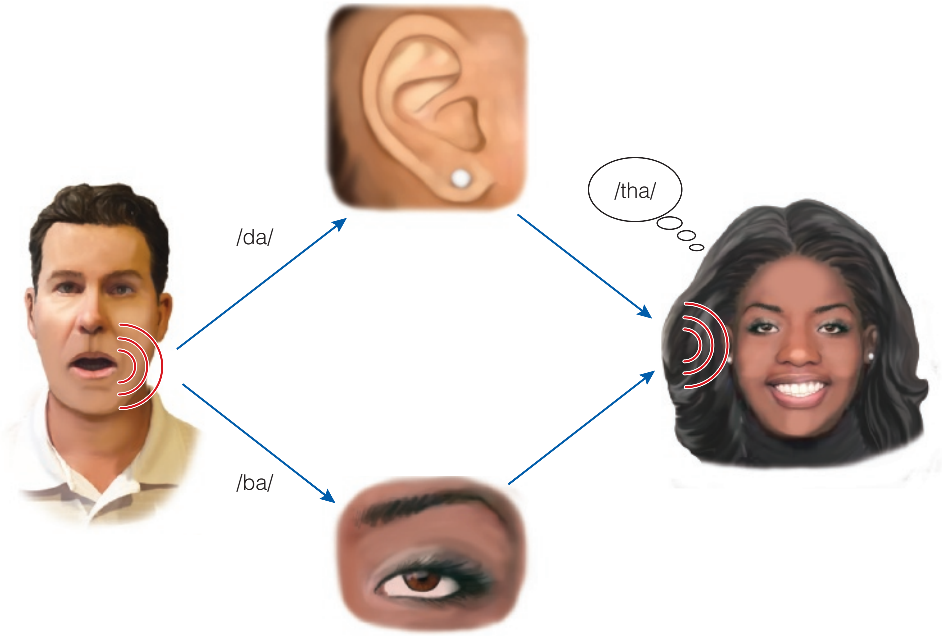
The View of Speech Perception as Special

Some researchers suggest that speech-perception processes differ from the processes we use when we hear other sounds. We will explore this view further in the next sections by reviewing research on categorical perception and the motor theory of speech perception.

Categorical Perception One phenomenon in speech perception that led to the notion of specialization was the finding of **categorical perception**—discontinuous categories of speech sounds (Bidelman, Moreno, & Alain, 2013). That is, although the speech sounds we actually hear are made up of a continuum of variation in sound waves, we experience speech sounds categorically. This phenomenon can be seen in the perception of the consonant–vowel combinations *ba, da*, and *ga*. A speech signal would look different for each of these syllables. Some patterns in the speech signal lead to the perception of *ba*. Others lead to the perception of *da*. And still others lead to the perception of *ga*.

Additionally, the sound patterns for each syllable may differ as a result of other factors like pitch. The *ba* that you said yesterday differs in pitch from the *ba* you say today. But it is not perceived as different: It is perceived as belonging to the same category as the *ba* you said a few days ago or will say tomorrow. However, two nonspeech sounds, such as two tones, would be perceived as different. In this case, continuous differences in pitch (how high or low the tone is) are heard as distinct tones.

In a classic study, researchers used a speech synthesizer to mimic this natural variation in syllable acoustic patterns. By this means, they also were able to control the acoustic difference between the syllables (Liberman et al., 1957). They created a series of consonant–vowel sounds whose objective sound waves changed in equal increments from *ba* to *da* to *ga*. People who listened to the synthesized syllables, however, heard a sudden switch from *ba* to *da* and from *da* to *ga*. Discrimination of differences within one sound category was relatively poor, whereas discrimination between categories



■ **Figure 9.2** **The McGurk Effect.** When we hear one sound but see the mouth of the speaker articulating a different sound, we are likely to perceive a compromise sound.

(e.g., between *ba* and *da*) was enhanced. Because people experienced continuous sound–wave differences as categorical, the researchers concluded that speech is perceived via specialized processes.

■ Explore Lab 39, Categorical Perception, Identification and Lab 40, Categorical Perception, Discrimination, in CogLab.

Coordinating Visual and Auditory Perception When we listen to someone speak, we do not rely solely on the auditory signals we hear. We also use visual input to understand others. The *McGurk effect* demonstrates powerfully how we integrate what we hear with what we see (see Figure 9.2 ■; McGurk & MacDonald, 1976; Tiippana, 2014). It involves the synchrony of visual and auditory perceptions: When watching a movie, an auditory syllable is perceived differently depending on whether you see the speaker make the sound that matches the pronunciation of the syllable or make another sound that does not match the syllable spoken. Imagine yourself watching a movie. As long as the soundtrack corresponds to the speakers' lip movements, you encounter no problems. Suppose, however, that the soundtrack indicates one thing, such as *da*. At the same time, the actor's lips clearly make the movements for another sound, such as *ba*. You are likely to hear a compromise sound, such as *tha*. It is neither what was said nor what was seen. You somehow synthesize the auditory and visual information. You thereby come up with a result that is unlike either. For this reason, poorly dubbed movies can be confusing. You are vaguely aware that the lips are saying one thing, and you are hearing something else entirely.

In one set of studies, Nicholls, Searle, and Bradshaw (2004) studied the McGurk effect with respect to lip reading. The experimenters covered half of the speaker's mouth, while either matching or mismatching auditory and visual information. The experimenters found that when the left side of the mouth was covered, little changed in the occurrence of the McGurk effect. When the right side of the mouth was covered, however, the occurrence of the McGurk effect dropped dramatically. The researchers then used an inverted video of the left side of the mouth, such that it appeared to be the right side of the mouth, and saw the McGurk effect rebound (Nicholls, Searle, & Bradshaw, 2004).

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These findings suggest that the right side, or what is perceived as the right side of the mouth, is attended to more in lip reading. Hence, lack of correspondence between what the right side of the mouth says and what is heard are the more likely to lead to the McGurk effect.

The McGurk effect seems to have a physiological basis in the superior temporal sulcus (STS). Researchers presented their participants with stimuli like the ones described previously that evoke the McGurk effect. However, when they used transcranial magnetic stimulation (TMS) to interrupt activity of the STS in their participants, the likelihood of the McGurk effect was significantly reduced (Beauchamp, Nath, & Pasalar, 2010).

In a recent study, researchers had participants listen to continuous acoustic signals. As we know from the section on categorical perception, people categorize continuous sounds as syllables like “ga” and “ba.” With repetitive transcranial magnetic stimulation (rTMS), participants’ lip representation in the primary motor cortex was then interrupted. With the motor cortex’s lip representation impaired, participants had a much harder time distinguishing between speech sounds that involved the lips or tip of the tongue in their articulation (e.g., *ba* and *da*). However, differentiation between sounds that do not involve lip articulation (e.g., *ka* and *ga*) was not impaired. These findings support the notion that motor parts of the cortex are involved not only in the production of speech but also in speech perception (Moettoenen & Watkins, 2009).

In normal conversation, we use lip reading to augment our perception of speech. The tendency to rely on visual speech (i.e., people’s lips and faces as they speak) appears to get stronger as we age: In one study, older adults were more influenced by visual speech than younger participants (Sekiyama, Sosho, & Sakamoto, 2014). It is particularly important in situations in which background noise may make speech perception more difficult.

Is it possible to combine the opposing views of speech perception as ordinary or special? Perhaps one reason for the complexity of this issue lies in the nature of speech perception itself. It involves both linguistic and perceptual attributes. From a purely perceptual perspective, speech is just a relatively complex signal that is not treated qualitatively differently from other signals. From a psycholinguistic perspective, speech is special because it lies within the domain of language, a special human ability. Indeed, cognitive psychology textbooks differ in terms of where speech perception is discussed. Sometimes it is discussed in the context of language, other times in the context of perception. Thus, the diversity of views on the nature of speech perception can be seen as reflecting the differences in how researchers

INVESTIGATING COGNITIVE PSYCHOLOGY

Understanding Schemas

Ask a friend to do an experiment with you. Tell your friend that you are going to say a sentence and ask them what it means. Say the following sentence to your friend: “In mud eels are, in clay none are.” Ask your friend the meaning of what you just said.

Chances are that your friend did not understand the sentence. Why? Your friend was not applying the appropriate schema to understand your utterance. Ask your friend to think of him- or herself as a fish who doesn’t want to be eaten by eels. Now, repeat this sentence to your friend. Can your friend understand the sentence now? Many people can after they have the context. (Although, some people still will not be able to understand this utterance, so you will have to give them stronger hints.)

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treat speech. They view it either as regular acoustic signals or as more special phonetic messages (Remez, 1994).

Understanding Meaning: Semantics

> *Language is very difficult to put into words.*
>
> —Voltaire

The opening of this chapter quoted Helen Keller's description of her first awareness that words had meanings. You probably do not remember the moment that words first came alive to you, but your parents surely do. In fact, one of the greatest joys of being a parent is watching your children's amazing discovery that words have meanings. **Semantics** is the study of meaning in a language. Semanticists are concerned with how words and sentences express meaning. In semantics, **denotation** is the strict dictionary definition of a word. **Connotation** is a word's emotional overtones, presuppositions, and other nonexplicit meanings. Taken together, denotation and connotation form the meaning of a word. Because connotations may vary between people, there can be variation in the meaning formed. Imagine the word *snake*. For many people, the connotation of *snake* is negative or dangerous. Others, for example, a biologist specializing in snakes (called a *herpetologist*), would have a different and probably much more positive connotation for the word *snake*.

How do we understand word meanings in the first place? Recall from previous chapters that we encode meanings into memory through concepts. These include ideas, to which we may attach various characteristics and with which we may connect various other ideas, such as through propositions (Rey, 2003). They also include images and perhaps motor patterns for implementing particular procedures. Here, we are concerned only with concepts, particularly in terms of words as arbitrary symbols for concepts.

Actually, when we think of words as representing concepts, words are economical ways to manipulate related information. For example, when you think about the single word *desk*, you also may conjure all of these:

- the instances of desks in existence anywhere
- the instances of desks that exist only in your imagination
- the characteristics of desks
- the things you might do with desks
- the other concepts you might link to desks (e.g., things you put on or in desks or places where you might find desks)

Having a word for something helps us to add new information to our existing information about that concept. For example, you have access to the word *desk*. When you have new experiences related to desks or otherwise learn new things about desks, you have a word around which to organize all this related information.

Recall, too, the constructive nature of memory. Having word labels (e.g., "washing clothes," "peace march") has several effects. First, it facilitates the ease of understanding and remembering a text passage. Second, it enhances subjects' recall of the shape of a droodle. (Recall that a droodle is essentially a doodle puzzle: You see a doodle and you have to guess what it is.) Third, it affects the accuracy of eyewitness testimony. Having words as concepts for things helps us in our everyday nonverbal interactions. For example, our concepts of *skunk* and of *dog* allow us more easily to recognize the difference between the two, even if we see an animal only for a moment (Ross & Spalding, 1994). Depending on which we saw, this rapid recognition enables us to respond appropriately. Clearly, being able to comprehend the conceptual meanings of words is important. But how do we retrieve the meanings of words?

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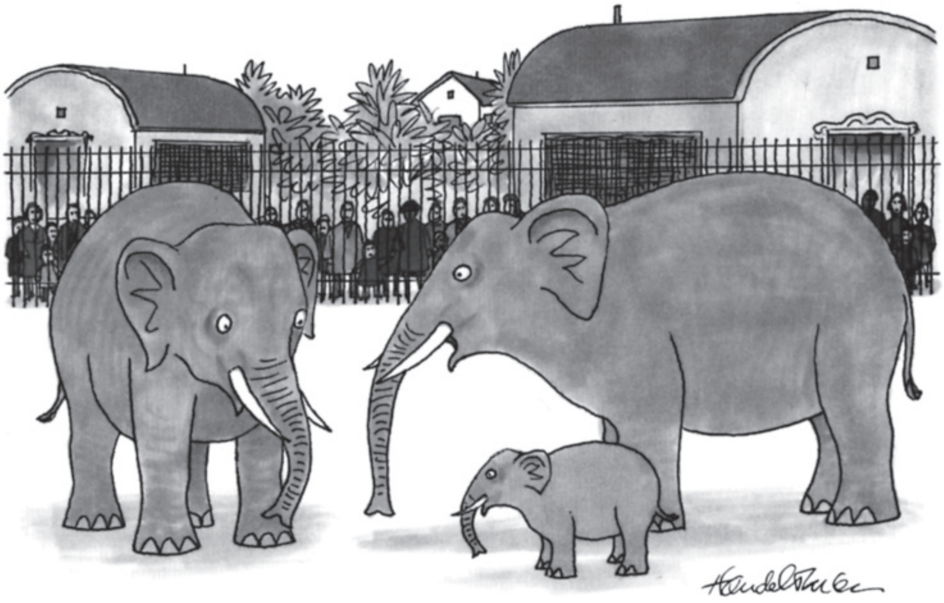
BELIEVE IT OR NOT | Can It Really Be Hard to Stop Cursing?

In psychology, the involuntary utterance of socially inappropriate words or sentences is called *coprolalia*. The range of other coprophenomena includes making socially inappropriate gestures (*copropraxia*) and drawings (*coprographia*). Often, these utterances are related to obscene, religious, or ethnical content. They are not expressed out of anger but rather result from a kind of urge that the speaker cannot control and that can cause him or her considerable embarrassment. Coprolalia is often part of a neurological disorder called *Tourette syndrome*, which exhibits a widely variable pattern of tics (like suddenly and involuntarily kicking in the air or pulling one's earlobe). Tourette syndrome usually starts in childhood and stabilizes after adolescence. Different tics seem to be caused by different brain mechanisms. Coprolalia, in particular, involves activation of the brain's language regions, caudate, thalamus, and cerebellum. It can also occur outside of Tourette syndrome in people who have suffered strokes or encephalitis (Freeman et al., 2008). Indeed, even cases of swearing in sign language among patients with Tourette syndrome have been reported.

All words are stored in our mental lexicon, which contains both the words and their meanings. One observation that hints at how we represent meaning comes from studies with people who once had normal language skills but at some point contracted lesions of the temporal lobes of the brain. When some of these people were asked to indicate the meaning of a picture, their problems in naming objects were not arbitrary. One group of patients had trouble recognizing animate things, like animals and plants. Another group of patients was challenged in recognizing things that were manufactured, like tools. Warrington and colleagues (Warrington & McCarthy, 1987; Warrington & Shallice, 1984) have suggested criteria for determining the difference between manufactured and living things. Objects that are made by humans are mostly distinguished by means of their function. Do we use an object to get from one point to another, or to open something? Living things, in contrary, are mainly distinguished by means of their looks. A horse looks different than a donkey, and both differ from what a cow looks like. So when



"'Born in conservation,' if you don't mind. 'Captivity' has negative connotations."

Published in *The New Yorker* 3/22/1993 by J.B. Handelsman/www.Cartoonbank.com

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we retrieve the meaning of words from our memory, we may rely on their perceptual features and the function (as well as some other characteristics). This interpretation is in line with the findings of the lesion studies: People who had sustained damage in regions that are involved in perceptual processing have trouble recognizing living things. People with lesions in areas that are involved in the processing of functional information have more trouble recognizing manmade things.

As you may have noticed, many words in English have more than one meaning: Take the word "foot," for example. "I have a very wide foot," refers to the foot as a body part. "She lives at the foot of the hill," indicates that a person is living at the bottom part of a hill. Generally, words have a dominant meaning that is used more often, and one or more subordinate meanings. In the example with the word "foot," people typically think of a body part, which is the dominant meaning. The bottom part of a hill is a subordinate meaning. What meaning you ultimately ascribe to the word depends largely on the context in which it appears.

Understanding Sentences: Syntax

An equally important part of the psychology of language is the analysis of linguistic structure. Not only words convey meaning; the structure of sentences does as well. For example, "The man hunted the lion." has a different meaning from "The lion hunted the man." *Syntax* is the systematic way in which words can be combined and sequenced to make meaningful phrases and sentences (Carroll, 1986). Whereas studies of speech perception chiefly investigate the phonetic structure of language, syntax focuses on the study of the grammar of phrases and sentences. In other words, it considers the regularity of structure.

Although you have heard the word *grammar* before in regard to how people should structure their sentences, psycholinguists use the word *grammar* in a slightly different way. Specifically, **grammar** is the study of language in terms of noticing regular patterns. These patterns relate to the functions and relationships of words in a sentence. They extend as broadly to the level of discourse and narrowly to the pronunciation and meaning of individual words.

In your English courses, you may have been introduced to *prescriptive grammar*. This kind of grammar prescribes the "correct" ways in which to structure the use of written and spoken language. Of greater interest to psycholinguists is *descriptive grammar*, in which an attempt is made to describe the structures, functions, and relationships of words in language.

Consider an example of a sentence that illustrates the contrast between prescriptive and descriptive approaches to grammar: When Mario observes his father carrying an unappealing bedtime book upstairs, he responds, "Daddy, what did you bring that book that I don't want to be read to out of up for?" (Pinker, 1994, p. 97). Mario's utterance might shiver the spine of any prescriptive grammarian. But Mario's ability to produce such a complex sentence, with such intricate internal interdependencies, would please descriptive grammarians.

The study of syntax allows analysis of language in manageable—and therefore relatively easily studied—units. Also, it offers limitless possibilities for exploration. There are virtually no bounds to the possible combinations of words that may be used to form sentences. Earlier, we referred to this property as the productivity of language. In English, as in any language, we can take a particular set of words (or morphemes, to be more accurate) and a particular set of rules for combining the items and produce a breathtakingly vast array of meaningful utterances. Suppose you went to the U.S. Library of Congress and randomly selected any sentence from any book. You then searched for an identical sentence among the vast array of other books. Aside from intentional quotations, you would likely not find the identical sentence.

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People demonstrate a remarkable knack for understanding syntactical structure. Read through the following demonstration in the *Investigating Cognitive Psychology: Your Sense of Grammar* box and try to find the sentences that are not grammatical.

INVESTIGATING COGNITIVE PSYCHOLOGY

Your Sense of Grammar

Mark an asterisk next to the sentences that are not grammatical, regardless of whether the sentences are meaningful or accurate:

1. The student the book.
2. Bought the book.
3. Bought the student the book.
4. The book was bought by the student.
5. By whom was the book bought?
6. By student the bought book.
7. The student was bought by the book.
8. Who bought the book?
9. The book bought the student.
10. The book bought.

Answers: 1, 2, 3, 6, 10

Fluent speakers of a language can recognize syntactical structure immediately, regardless of whether particular sentences and particular word orders are or are not grammatical (Bock, 1990; Pinker, 1994). We can do so even when the sentences are meaningless. For example, we can evaluate Chomsky's sentence, "Colorless green ideas sleep furiously." Or we can evaluate a sentence composed of nonsense words, as in Lewis Carroll's poem "Jabberwocky," "'Twas brillig and the slithy toves did gyre and gimble in the wabe."

Next, we explore the properties and impact of syntax in more detail. We have a look at the phenomena of syntactical priming and speech errors and consider two approaches to analyzing sentences: phrase-structure grammar and transformational grammar. We will also explore the interaction between words and sentence structures.

Syntactical Priming

Just as we show semantic priming of word meanings in memory (i.e., we react faster to words that are related in meaning to a prior presented word), we show syntactical priming of sentence structures. In other words, we spontaneously tend to use syntactical structures and read sentences faster that parallel the structures of sentences we have just heard (Bock, 1990; Bock, Loebell, & Morey, 1992; Sturt, Keller, & Dubey, 2010). For example, a speaker will be more likely to use a passive construction (e.g., "The student was praised by the professor") after hearing a passive construction. He or she will do so even when the topics of the sentences differ. Even children as young as age 3 years described a series of new items with the same sentence structure used by an experimenter (Bencini & Valian, 2008).

Another example of syntactical priming is sentence priming. In this type of experiment, participants are presented with a sentence. Participants then are presented with new sentences and are asked to rate the degree to which they are grammatically correct. If a sentence has the same structure as the previously presented item, it is rated as more nearly grammatically correct (Luka & Barsalou, 2005), independent of its actual degree of grammatical correctness. Participants in the experimental group may have read the sentence, "Amanda carried Fernando the package," whereas control-group participants read the sentence, "Amanda carried the package to Fernando." Both groups were then asked to rate the test sentence, "Igor lugged Dr. Frankenstein the corpse." As you can see, this sentence is structurally similar to the first sentence that participants in the experimental group were asked to read; it does not resemble the structure of the first sentence that control-group participants read. And, indeed, participants from the experimental group rated the test sentence as more grammatical than did control-group participants.

Speech Errors

Other evidence of our uncanny aptitude for syntax is shown in the *speech errors* we produce. Even when we accidentally switch the placement of two words in a sentence, we still form grammatical, if meaningless or nonsensical, sentences. We almost invariably switch nouns for nouns, verbs for verbs, prepositions for prepositions, and so on. For example, we may say, "I put the oven in the cake." But we will probably not say, "I put the cake oven in the." We usually even attach (and detach) appropriate **function morphemes** to make the switched words fit their new positions. For example, when meaning to say, "The butter knives are in the drawer," we may say, "The butter drawers are in the knife." Here, we change "drawer" to plural and "knives" to singular to preserve the grammaticality of the sentence. Even so-called *agrammatic aphasics*, who have extreme difficulties in both comprehending and producing language, preserve syntactical categories in their speech errors (Butterworth & Howard, 1987; Garrett, 1992). In Chapter 10, we consider slips of the tongue in more detail.

Analyzing Sentences: Phrase-Structure Grammar

The preceding examples seem to indicate that we humans have some mental mechanism for classifying words according to syntactical categories. This classification mechanism is separate from the meanings for the words (Bock, 1990). When we compose sentences, we seem to analyze and divide them into functional components. This process is called *parsing*. We assign appropriate syntactical categories (often called *parts of speech*, e.g., noun, verb, article) to each component of the sentence. We then use the syntax rules for the language to construct grammatical sequences of the parsed components.

Early in the 20th century, linguists who studied syntax largely focused on how sentences could be analyzed in terms of sequences of phrases, such as noun phrases and verb phrases, which were mentioned previously. They also focused on how phrases could be parsed into various syntactical categories, such as nouns, verbs, and adjectives. Such analyses look at the **phrase-structure grammar**—they analyze the structure of phrases as they are used. Let's have a closer look at the sentence:

"The girl looked at the boy with the telescope."

First of all, the sentence can be divided into the noun phrase (NP) "The girl" followed by a verb phrase (VP) "looked at the boy with the telescope." The noun phrase can be further divided into a determiner ("the") and a noun ("girl"). Likewise, the verb phrase can be further subdivided. However, the analysis of how to divide the verb phrase depends on what meaning the speaker had in mind. You may have noticed that the sentence can have two meanings:

(a) The girl looked with a telescope at the boy, or

(b) The girl looked at a boy who had a telescope.

In case (a), the verb phrase contains a verb (V; "looked"), and two prepositional phrases (PP; "at the boy" and "with the telescope"). In case (b), the verb phrase would again contain the verb "looked," but it has just one prepositional phrase ("looked at the boy with the telescope"). You can work your way further down and divide the prepositional

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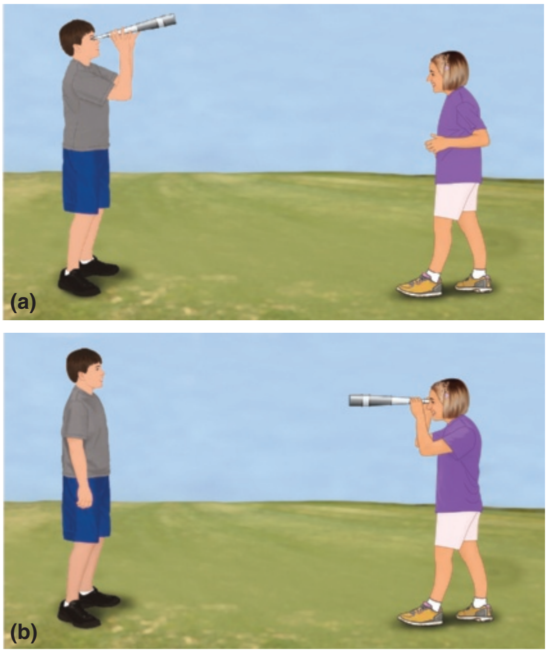
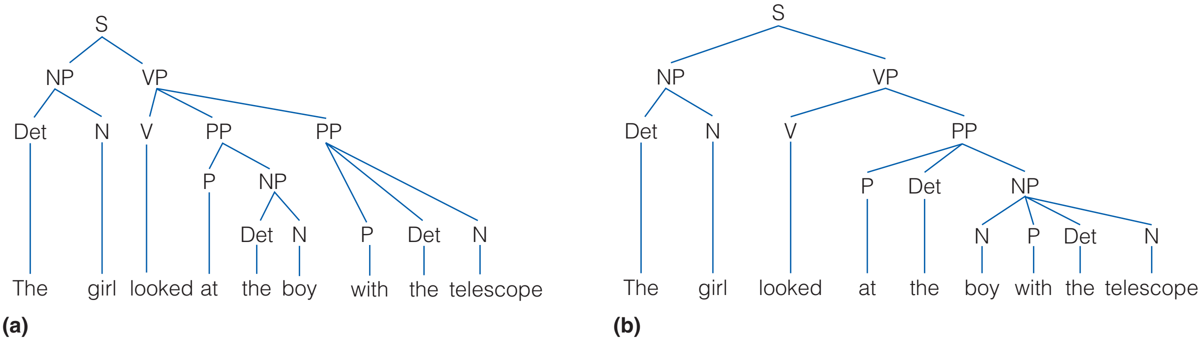


The sentence “The girl looked at the boy with the telescope” can be interpreted in two different ways.

phrases further into prepositions, determiners, nouns, and so on (see Figure 9.3 ■ for details).

The rules governing the sequences of words are termed *phrase-structure rules*. Linguists often use tree diagrams, such as the ones shown in Figure 9.3, to observe the interrelationships of phrases within a sentence. Various other models also have been proposed (e.g., relational grammar, Farrell, 2005; Perlmutter, 1983a; lexical functional grammar; Bresnan, 1982).

Tree diagrams help to reveal the interrelationships of syntactical classes within the phrase structures of sentences (Clegg & Shepherd, 2007; Wasow, 1989). In particular, such diagrams show that sentences are not merely organized chains of words, strung together sequentially. Rather, they are organized into hierarchical structures of embedded phrases. The use of tree diagrams helps to highlight many aspects of how we use language, including both our linguistic sophistication and our difficulties in using language. As you can see in Figure 9.3, our example sentence is depicted in two different



■ Figure 9.3 Phrase-Structure Grammar (part 1). Phrase-structure grammar illustrates the hierarchies of phrases within sentences. Here you can see two possible ways to analyze the following sentence: “The girl looked at the boy with the telescope.” The abbreviations used in the tree diagrams are S (sentence), NP (noun phrase), VP (verb phrase), PP (prepositional phrase), N (noun), V (verb), Det (determiner), and P (preposition).

INVESTIGATING COGNITIVE PSYCHOLOGY

Syntax

Using the following 10 words, create 5 strings of words that make grammatical sentences. Also create five sequences of words that violate the syntax rules of English grammar: *ball, basket, bounced, into, put, red, rolled, tall, the, woman*.

Finished? Now think about the steps involved in producing the sentences. To complete the preceding task, you mentally classified the words into syntactical categories, even if you did not know the correct labels for the categories. You then arranged the words into grammatical sequences according to the syntactical categories for the words and your implicit knowledge of English syntax rules. Most 4-year-olds can demonstrate the same ability to parse words into categories and to arrange them into grammatical sentences. Of course, most 4-year-olds probably cannot label the syntactical categories for any of the words.

ways, depending on its meaning. By observing tree diagrams of ambiguous sentences, psycholinguists can better pinpoint the source of confusion.

A New Approach to Syntax: Transformational Grammar

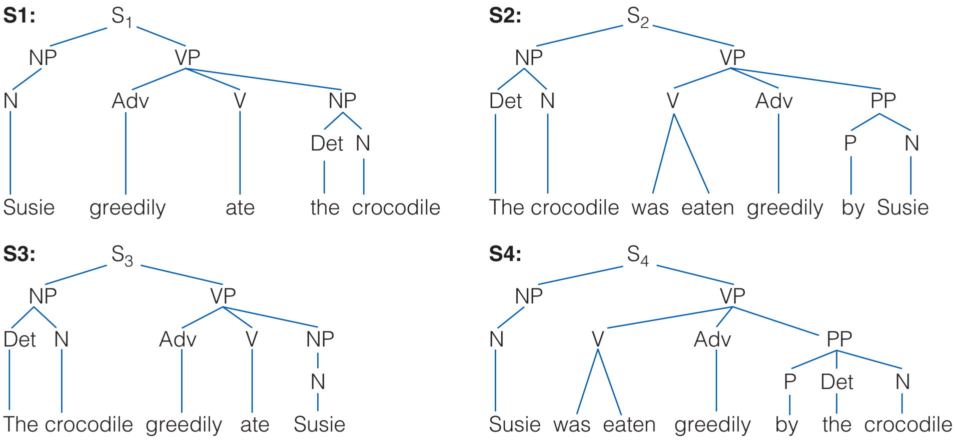
In 1957, Noam Chomsky revolutionized the study of syntax. He suggested that to understand syntax, we must not only observe the interrelationships among phrases within sentences but also consider the syntactical relationships between sentences. Specifically, Chomsky observed that particular sentences and their tree diagrams show peculiar relationships.

For example, consider the following sentences:

S_1: Susie greedily ate the crocodile.

S_2: The crocodile was eaten greedily by Susie.

Oddly enough, a phrase-structure grammar would not show any particular relation at all between sentences S1 and S2. Indeed, phrase-structure analyses of S1 and S2 would look almost completely different (Figure 9.4 ■). Yet, the two sentences differ



■ **Figure 9.4** **Phrase-Structure Grammar (part 2).** Phrase-structure grammar shows surprising dissimilarities between sentences S1 and S2, yet surprising similarities between S1 and S3 or between S2 and S4. Noam Chomsky suggested that to understand syntax, we also must consider a way to view the interrelationships among various phrase structures.

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only in voice. The first sentence is expressed in the active voice and the second in the passive voice. But both sentences represent the same proposition "ate (greedily) (Susie, crocodile)." Recall from Chapter 7 that propositions may be used to illustrate that the same underlying meanings can be derived through alternative means of representation.

Consider another pair of sentences that have the same meaning:

S_3: The crocodile greedily ate Susie.

S_4: Susie was eaten greedily by the crocodile.

Again, the sentences have the same meaning, but phrase-structure grammar would show no relationship between S3 and S4. What's more, phrase-structure grammar would show some similarities of surface structure between S1 and S3 as well as S2 and S4. The pairs of sentences clearly have quite different meanings, particularly to Susie and the crocodile. Apparently, an adequate grammar would address the fact that sentences with similar surface structures can have very different meanings.

Chomsky (1957) suggested a way to supplement the study of phrase structures. He proposed the study of **transformational grammar**, which involves transformational rules. These rules guide the ways in which an underlying proposition can be arranged into a sentence. Obviously, many different sentences can express the same proposition. Transformational grammar considers how the tree-structure diagrams in Figure 9.4 are interrelated. With application of transformational rules, the tree structure of S1 can be mapped onto the tree structure of S2. Similarly, the structure of S3 can be mapped onto the tree structure of S4.

In transformational grammar, **deep structure** refers to an underlying syntactical structure that links various phrase structures through various transformation rules. In contrast, **surface structure** refers to any of the various phrase structures that may result from such transformations. Many casual readers of Chomsky have misunderstood Chomsky's terms. They incorrectly inferred that deep structures refer to profound underlying meanings of sentences, whereas surface structures refer only to superficial interpretations of sentences. This is not the case. Chomsky meant only to show that differing phrase structures may have a relationship that is not immediately apparent by using phrase-structure grammar alone. For example, the sentences, "Susie greedily ate the crocodile," and "The crocodile was eaten greedily by Susie" have a relationship that cannot be seen just by looking at the phrase-structure grammar. To detect the underlying relationship between two phrase structures, transformation rules must be applied.

Relationships between Syntactical and Lexical Structures

Chomsky (1965, cited in Wasow, 1989) also addressed how syntactical structures may interact with words (lexical structures). He suggested that our mental lexicon contains more than the semantic meanings attached to each word (or morpheme). In addition, each lexical item also contains syntactical information. This syntactical information for each lexical item indicates three things:

- the syntactical category of the item, such as noun versus verb;
- the appropriate syntactical contexts in which the particular morpheme may be used, such as pronouns as subjects versus as direct objects; and
- idiosyncratic information about the syntactical uses of the morpheme, such as the treatment of irregular verbs.

For example, there would be separate lexical entries for the word *spread* categorized as a noun and for *spread* as a verb. Each lexical entry also would indicate which syntactical rules to use for positioning the word. The rules that are applicable depend on which category is applicable in the given context. For example, as a verb, *spread* would not follow the

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article *the*. As a noun, however, spread would be allowed to do so. Even the peculiarities of syntax for a given lexical entry would be stored in the lexicon. For example, the lexical entry for the verb *spread* would indicate that this verb deviates from the normal syntactical rule for forming past tenses by adding *-ed* to the stem used for the present tense.

You may wonder why we would clutter up our mental lexicon with so much syntactical information. The ability to attach syntactical, context sensitive, and idiosyncratic information to the items in our mental lexicon has an advantage. If we add to the complexity of our mental lexicon, we can simplify drastically the number and complexity of the rules we need in our mental syntax. For example, by attaching information about the idiosyncratic treatment of irregular verbs (e.g., *spread* or *fall*) to our mental lexicon, we do not have to endure different syntactical rules for each verb. By making our lexicon more complex, we allow our syntax to be simpler. In this way, appropriate transformations may be simple and relatively context free. Once we know the basic syntax of a language, we easily can apply the rules to all items in our lexicon. We then can gradually expand our lexicon to provide increasing complexity and sophistication.

Not all cognitive psychologists agree with all aspects of Chomsky's theories (e.g., Bock, Loebell, & Morey, 1992; Devitt, 2008; Garrett, 1992; Jackendoff, 1991). Many particularly disagree with his emphasis on syntax (form) over semantics (meaning). The suggestion that syntactic rules influence the creation of a deep structure, which is then transformed through the application of more rules into a surface structure, left psychologists wondering about the significance of meaning. A theory that put so much emphasis on syntax seemed insufficient to explain the processes of how we use language to express meaning. Nonetheless, several cognitive psychologists have proposed models of language comprehension and production that include key ideas of syntax.

practical applications of **COGNITIVE PSYCHOLOGY**

Speaking with Non-Native English Speakers

Given what you now know about processes of speech perception, semantics, and syntax, think about ways to make your speech production easier for others to perceive. If you are speaking to someone whose primary language differs from yours, try slowing down your speech, thus exaggerating the length of time between words. Be sure to enunciate consonant sounds carefully, without making your vowel sounds too long. Use simpler sentence constructions. Break down lengthy and involved sentences into smaller units. Insert longer pauses between sentences to give the person time to translate the sentence into propositional form. Communication may feel more effortful but probably will be more effective.

Think about conversations with people who suffer from hearing impairments. How can you help them understand you? Do you apply the same strategies as with foreigners, or maybe some others?

How do we link the elements in our mental lexicon to the elements in our syntactical structures? Various models for such bridging have been proposed (Bock, Loebell, & Morey, 1992; Culicover & Jackendoff, 2005; Jackendoff, 1991). According to some of these models, when we parse sentences by syntactical categories, we create slots for each item in the sentence. Consider, for example, the sentence, "Juan gave María the book from the shelf." There is a slot for a noun used as

(1) a subject (Juan),

(2) a direct object (the book),

(3) an indirect object (María), and

(4) objects of prepositions (the shelf).

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in the lab of STEVEN PINKER

I have always thought of language as a window into human nature. Early in my career, I tried to identify the mental mechanisms that children use to acquire their mother tongue as a way of shedding light on the nature–nurture debate. I then focused on the meaning and syntax of verbs—why you can pour water into a glass, but you can't pour a glass with water, and why you can fill a glass with water, but you can't fill water into a glass—to illuminate the basic concepts of human thought such as causation, agency, space, time, and substance. For a number of years, I studied regular verbs like *walk-walked* and *play-played* to get insight about the computational architecture of human cognition, and how they differ from irregular verbs like *sing-sang* and *bring-brought* to understand the interaction between computation and memory.

Steven Pinker

Courtesy of the author

Currently, I am using "indirect speech"—innuendo, euphemism, doublespeak, shilly-shallying—as a window into social relationships. People often don't blurt out what they mean in so many words, but instead they veil their intentions in innuendo, counting on their listeners to "catch their drift" or "read between the lines." Here are some examples:

- If you could pass the guacamole, that would be awesome. [a polite request]
- Gee, officer, is there some way we could take care of the ticket right here, without going to court or doing a lot of paperwork? [a bribe]
- Would you like to come up and see my etchings? [a sexual come-on]
- I hear you're the jury foreman in the Soprano trial. It's an important civic responsibility. You've got a wife and kids. We know you'll do the right thing. [a threat]

Why don't people just say what they mean? The reason, I believe, is that language has to do two things at once: convey a proposition, and maintain social relationships. The anthropologist Alan Fiske has found that in every culture, the relationship between two people falls into a small number of types: communality (warmth and sharing), dominance, and reciprocity (tit-for-tat exchanges or equal distribution of resources). We distinguish these sharply. For example, everyone knows that good friends shouldn't engage in a business transaction, like one selling his car to the other, because the act of negotiating a price (reciprocity) clashes with the rules of a friendship (communal sharing), putting a strain on the relationship. The problem with language is that the very act of making a request in words can clash with the ongoing relationship type: an imperative like "Give me the guacamole" assumes a dominance relationship (you're bossing someone around), which clashes with friendship; a bribe like "If I give you $50, will you let me drive away?" treats the officer as a business customer rather than a superior. So to treat your fellow diner as an equal, or to probe whether the officer is receptive to a bribe, without challenging the current relationship, people use indirect speech. Basically, they are seeking plausible deniability of a transaction that presupposes a different relationship model than the one currently in force.

We test this idea by having people imagine themselves in the shoes of someone receiving a bribe, a threat, or a sexual come-on that is posed either directly or with innuendo, and then ask them to indicate how confident they are in what they think the speaker intends, whether they feel threatened or offended, how easy it would be to resume a normal relationship if the offer is rebuffed, and other questions. We also have people role-play these interactions while hooked up to electrophysiological recording equipment to measure their sense of threat and challenge in measures such as heart rate and blood pressure.

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There are also slots for the verb, the preposition, and the articles.

In turn, lexical items contain information regarding the kinds of slots into which the items can be placed. The information is based on the kinds of thematic roles the items can fill. **Thematic roles** are ways in which items can be used in the context of communication. Several roles have been identified. In particular, these roles are as follows:

- the agent, the "doer" of any action
- the patient, the direct recipient of the action

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- the beneficiary, the indirect recipient of the action
- the instrument, the means by which the action is implemented
- the location, the place where the action occurs
- the source, where the action originated
- the goal, where the action is going (Bock, 1990; Fromkin & Rodman, 1988)

According to this view of how syntax and semantics are linked, the various syntactical slots can be filled by lexical entries with corresponding thematic roles. For example, the slot of subject noun might be filled by the thematic role of agent. Nouns that can fill agent roles can be inserted into slots for subjects of phrases. Patient roles correspond to slots for direct objects. Beneficiary roles fit with indirect objects, and so on.

CONCEPT CHECK

1. What is coarticulation, and why is it important?
2. What does the view of speech perception as ordinary suggest?
3. What is categorical perception?
4. What is syntactical priming?
5. What is the difference between phrase-structure grammar and transformational grammar?

Reading

Reading is a complex process that involves, at minimum, perception, language, memory, thinking, and intelligence (Adams, 1990, 1999; Garrod & Daneman, 2003; Smith, 2004). You have to recognize the letters on this page, put them together to form words that have meaning, keep their meaning in memory until you have finished reading the sentence or even paragraph, and think about what message the writer tried to communicate to you. Although so many different processes are going on, we read with remarkable speed and accuracy: The average adult reads prose at about 250 to 300 words per minute.

In a typical day, we repeatedly encounter written language. Every day we see signs, billboards, labels, and notices. These items contain a wealth of information that helps us make decisions and understand situations. As a result, the ability to read is fundamental to our everyday lives.

In the following section, we examine three different processes that contribute to our ability to read: perceptual, lexical, and comprehension processes. Then we will discuss dyslexia, a condition in which people have trouble reading.

Perceptual Issues in Reading

A basic but important step in reading is the activation of our ability to recognize letters. When you are reading, you somehow manage to perceive the correct letter when it is presented in a wide array of typestyles and typefaces. For example, you can perceive it correctly in capital and lowercase forms, and even in cursive forms. Such aspects are called *orthographic*. You then must translate the letter into a sound, creating a phonological code (relating to sound). This translation is particularly difficult in English because English does not always ensure a direct correspondence between a letter and a sound. George Bernard Shaw, playwright and lover of the English language, observed the illogicality of English spellings. He suggested that, in English, it would be perfectly reasonable to pronounce *ghoti* as *fish.* You would pronounce the *gh* as in *rough*, the *o* as in *women*, and the *ti* as in *nation*. That brings up another perplexing "Englishism": How do you pronounce *ough*? Try the words *dough, bough, bought, through*, and *cough*—had *enough?*

After you somehow manage to translate all those visual symbols into sounds, you must sequence those sounds to form a word (Pollatsek & Miller, 2003). Then you need to identify the word and figure out what the word means. Ultimately, you move on to the next word and repeat the process all over again. You continue this process with subsequent words to formulate a single sentence. You continue this process for as long as you read. Clearly, the normal ability to read is not at all simple. About 50% of American adults cannot read a book written at eighth-grade level (Literacy Project Foundation, 2014).

When learning to read, novice readers must come to master two basic kinds of processes: lexical processes and comprehension processes. **Lexical processes** are used to identify letters and words. They also activate relevant information in memory about these words. **Comprehension processes** are used to make sense of the text as a whole (and are discussed later in this chapter). The separation and integration of both bottom-up and top-down approaches to perception can be seen as we consider the lexical processes of reading.

Lexical Processes in Reading

We are about to explore, in more detail, the lexical processes involved in reading. First, we take a closer look at fixations in our eye movements that help us read. Then, we discuss how we identify words so we can retrieve their meaning from our memory (lexical access); and, finally, we consider the connection between lexical-access speed and intelligence.

Fixations and Reading Speed

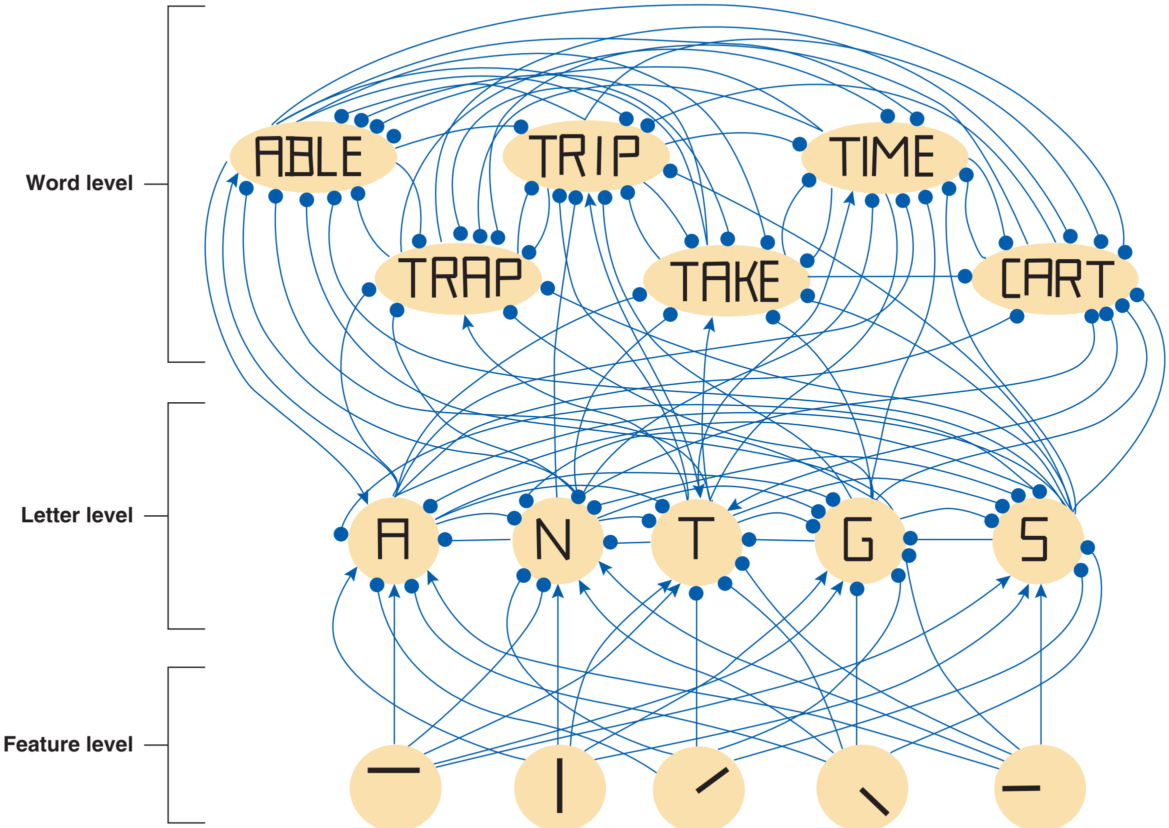
When we read, our eyes do not move smoothly along a page or even along a line of text. Rather, our eyes move in *saccades*—rapid sequential movements—as they fixate on successive clumps of text. The fixations are like a series of "snapshots" (Pollatsek & Rayner, 1989) and are of variable length (Carpenter & Just, 1981). Readers fixate for a longer time on longer words than on shorter words. They also fixate longer on less familiar words (i.e., words that appear less frequently in the English language) than on more familiar words (i.e., words of higher frequency). The last word of a sentence also seems to receive an extra long fixation time. This can be called "sentence wrap-up time" (Carpenter & Just, 1981; Warren, White, & Reichle, 2009).

Although most words are fixated, not all of them are. Readers fixate up to about 80% of the content words in a text. These words include nouns, verbs, and other words that carry the bulk of the meaning. (Function words, such as *the* and *of*, serve a supporting role to the content words.) Just what is the visual span of one of these fixations? It appears that we can extract useful information from a perceptual window of characters about 4 characters to the left of a fixation point and about 14 or 15 characters to the right of it. These characters include letters, numerals, punctuation marks, and spaces. Saccadic movements leap an average of seven to nine characters between successive fixations. So some of the information we extract may be preparatory for subsequent fixation (Pollatsek & Rayner, 1989; Rayner et al., 1995). When students speed-read, they show fewer and shorter fixations (Just, Carpenter, & Masson, 1982). But apparently their greater speed is at the expense of comprehension of anything more than just the gist of the passage (Homa, 1983).

Lexical Access

An important aspect of reading is **lexical access** the identification of a word that allows us to retrieve the meaning of the word from memory. Most psychologists who study reading believe that lexical access is an interactive process. It combines information of different kinds, such as the features of letters, the letters themselves, and the words comprising the letters (Morton, 1969).

Investigators (McClelland, Mirman, & Holt, 2009; Rumelhart & McClelland 1981, 1982) developed an interactive-activation model suggesting that activation of particular lexical elements occurs at multiple levels. Moreover, activity at each of the levels is interactive (Figure 9.5 ■).



■ **Figure 9.5 Word Recognition.** David Rumelhart and James McClelland used this figure to illustrate how activation at the feature level, the letter level, and the word level may interact during word recognition. In this figure, lines terminating in arrows prompt activation, and lines terminating in dots (blue circles) prompt inhibition. For example, the feature for a solid horizontal bar at the top of a letter leads to activation of the T character but to inhibition of the N character. Similarly, at the letter level, activation of T as the first letter leads to activation of TRAP and TRIP but to inhibition of ABLE. Going from the top down, activation of the word TRAP leads to inhibition of A, N, G, and S as the first letter but to activation of T as the first letter.

Source: Based on Richard E. Mayer, "The Search for Insight: Grappling with Gestalt Psychology's Unanswered Questions," in *The Nature of Insight,* edited by R. J. Sternberg and J. E. Davidson. Copyright © 1995 MIT Press.

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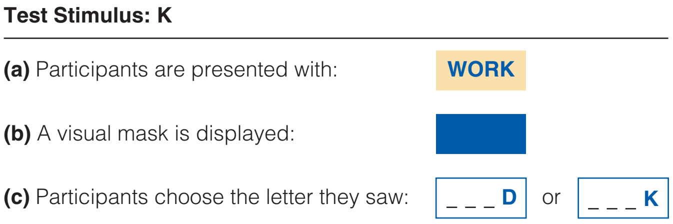
The interactive-activation model distinguishes among three levels of processing following visual input—the feature level, the letter level, and the word level. The model assumes that information at each level is represented separately in memory. Information passes from one level to another bidirectionally. In other words, processing occurs in each of two directions. First, it is bottom-up, starting with sensory data and working up to higher levels of cognitive processing. Second, it is top-down, starting with high-level cognition operating on prior knowledge and experiences related to a given context. The interactive view implies that we not only use the visually or orally perceptible features of letters to help us identify words but also the features we already know about words to help us identify letters. For this reason, the model is referred to as "interactive" (Plaut et al., 1996).

Other theorists have suggested alternatives to Rumelhart and McClelland's model (e.g., Meyer & Schvaneveldt, 1976; Paap et al., 1982), but the distinctions among interactive models go beyond the scope of this introductory text. Support for word-recognition models involving discrete levels of processing comes from studies of cerebral processing (Harley, 2008; Petersen et al., 1988; Posner et al., 1988, 1989). Studies that map brain metabolism via PET and fMRI (see Chapter 2) indicate that different regions of the brain become activated during passive visual processing of word forms, as opposed to semantic analysis of words or even spoken pronunciation of the words.

In addition to neuropsychological support, a number of word-recognition models have been simulated on computers (e.g., Harm & Seidenberg, 2004). Both models aptly predicted a word-superiority effect as well as a pseudo word-superiority effect. The word-superiority effect is similar to the *configural-superiority effect* and the *object-superiority effect* (mentioned in regard to top-down influences on perception). In the **word-superiority effect**, letters are read more easily when they are embedded in words than when they are presented either in isolation or with letters that do not form words. People take substantially longer to read unrelated letters than to read letters that form a word (Cattell, 1886). This effect is sometimes called the *Reicher-Wheeler effect*, named for two researchers who did early investigations of this effect (Reicher, 1969; Wheeler, 1970).

To observe the word-superiority effect, researchers use an experimental paradigm called the *lexical-decision task*. In this paradigm, a string of letters is presented briefly. It then is either removed or covered by a *visual mask*, a pattern that wipes out the previously presented stimulus from iconic memory (see Chapter 5 for more information about the iconic memory store). The participant then is asked to make a decision about whether the string of letters is a word.

To observe the word-superiority effect, the standard lexical-decision task is modified to examine the processing of letters (see Figure 9.6 ■). Participants are more accurate in


Test Stimulus: K
(a) Participants are presented with:
WORK
(b) A visual mask is displayed:
(c) Participants choose the letter they saw:
_ _ _ D
or
_ _ _ K

■ **Figure 9.6 Lexical-Decision Task.**

(a) Participants are presented briefly with a word (*WORK*) that contains the letter that is to be remembered (in this case, the letter *K*). However, participants do not know which of the letters presented they will have to remember.

(b) After the presentation of the word, a visual mask is displayed.

(c) Participants choose which one of two presented letters they saw before. Both letters *D* and *K* correspond to words (*word* and *work*).

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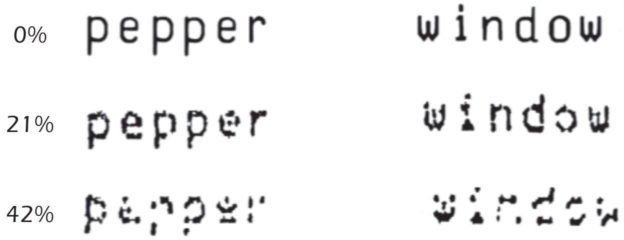

■ **Figure 9.7** **Word Degradation.** This figure shows instances of the word "window" and of the word "pepper," in which each word is clearly legible, somewhat legible, or almost completely illegible. Percentages indicate degree of degradation.

choosing the correct letter when it is presented in the context of a word than they are in choosing the correct letter when it is presented in isolation (Johnston & McClelland, 1973). Even letters in pronounceable pseudo words (e.g., "MARD") are identified more accurately than letters in isolation. However, strings of letters that cannot be pronounced as words (e.g., "ORWK") do not aid in identification (Grainger et al., 2003; Pollatsek & Rayner, 1989). ■ Explore Lab 44, Word Superiority, in CogLab.

There is also a *sentence-superiority effect* (Cattell, 1886; Perfetti, 1985): People take about twice as long to read unrelated words as to read words in a sentence (Cattell, 1886). The sentence-superiority effect can be seen in other paradigms as well. For example, suppose that a reader briefly sees a degraded stimulus. The word *window*, for example, might be shown but in degraded form (Figure 9.7 ■). When the word is standing by itself in this form, it is more difficult to recognize than when it is preceded by a sentence context. An example of such a context would be, "There were several repair jobs to be done. The first was to fix the ______." (Perfetti, 1985). Having a meaningful context for a stimulus helps the reader to perceive it.

Context effects work at both conscious and preconscious levels. At the conscious level, we have active control over the use of context to determine word meanings. At the preconscious level, the use of context is probably automatic and outside our active control. Participants seem to make lexical decisions more quickly when presented with strings of letters that commonly are associated pairs of words (e.g., "doctor" and "nurse" or "bread" and "butter"). They respond more slowly when presented with unassociated pairs of words, with pairs of nonwords, or with pairs involving a word and a nonword (Hyoenae, J., & Lindeman, 2008; Meyer & Schvaneveldt, 1971; Schvaneveldt, Meyer, & Becker, 1976). ■ Explore Lab 42, Lexical Decision, in CogLab.

Teaching How to Read

In the English language, there are several approaches to teach children how to read. Some of the basic ones are the whole-word approach, the whole-language approach, and the phonics approach. In the phonics approach, children are taught how the letters of the alphabet sound and then progressively put them together to read two letters together, then three, and so on. In the beginning, only regular words are used that are pronounced as they are spelled. The whole-word approach teaches children to recognize whole words, without the analysis of the sounds that make up the word. Proponents of this approach consider it more interesting for young children than learning about phonics. And finally, the whole-language approach argues that words are pieces of sentences and reading should therefore be taught in connection with entire sentences. So children start to read by reading sentences rather than words. The teacher may assist them to read the same poem or story over and over again.

When Reading Is a Problem—Dyslexia

People who have **dyslexia**—difficulty in deciphering, reading, and comprehending text—can suffer greatly in a society that puts a high premium on fluent reading (Sternberg & Spear-Swerling, 1999; Terras, Thompson, & Minnis, 2009). Problems in phonological processing, and thus in word identification, pose "the major stumbling block in learning to read" (Pollatsek & Rayner, 1989, p. 403; see also Grodzinsky, 2003). Several different processes may be impaired in dyslexia:

- *Phonological awareness*, which refers to awareness of the sound structure of spoken language (recognizing the different sounds that make up a word).
- *Phonological reading*, which entails reading words in isolation. Individuals with dyslexia often have more trouble recognizing the words in isolation than in context.
- *Phonological coding* in working memory. When people have difficulty storing phonemes in working memory and tend to confuse them more often, reading becomes increasingly difficult.
- *Lexical access*, which entails one's ability to retrieve phonemes from long-term memory. For example, how fast can a reader recognize the word pond when he sees it?

There are several different kinds of dyslexia. The most common ones are developmental dyslexia, which starts in childhood (Shaywitz & Shaywitz, 2005), and acquired dyslexia, which is the result of a traumatic brain injury (Coslett, 2003).

Developmental dyslexia is believed to have both biological and environmental causes. A major dispute in the field is the role of each. People with developmental dyslexia often have been found to have abnormalities in certain chromosomes, most notably, 3, 6, and 15 (Paracchini, Scerri, & Monaco, 2007). Neuropsychological studies suggest that readers with dyslexia exhibit hypoactivation (i.e., too little activation) in their left temporoparietal cortex as compared with regular readers. Other brain regions show atypical activation in dyslexic readers, for example, the left prefrontal region (linked with working memory), the left middle and superior temporal gyri (linked with receptive language), and the left occipitotemporal regions (associated with the visual analysis of letters; Gabrieli, 2009). Educational interventions, however, can help reduce the impairments in reading caused by dyslexia (Bakker, 2006).

CONCEPT CHECK

1. Which processes can be impaired in dyslexia?
2. What is lexical access?
3. Give an example for the word-superiority effect.

Understanding Conversations and Essays: Discourse

The preceding sections discussed, at a general level, aspects of how we understand written and spoken language. In our understanding of language, however, not only do words and sentences play a role, but so, too, does the greater context in which they appear. This section discusses more specifically the processes involved in understanding and using language in the greater context in which we encounter it. **Discourse** involves units of language larger than individual sentences—in conversations, lectures, stories, essays,

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INVESTIGATING COGNITIVE PSYCHOLOGY

Discourse

The following series of sentences is taken from a short story by O. Henry (William Sydney Porter, 1899–1953) titled "The Ransom of Red Chief." Actually, the following sequence of sentences is incorrect. Without knowing anything else about the story, try to figure out the correct sequence of sentences.

1. The father was respectable and tight, a mortgage financier and a stern, upright collection-plate passer and forecloser.
2. We selected for our victim the only child of a prominent citizen named Ebenezer Dorset.
3. We were down South in Alabama—Bill Driscoll and myself—when this kidnapping idea struck us.
4. Bill and me figured that Ebenezer would melt down for a ransom of two thousand dollars to a cent.

Hint: O. Henry was a master of irony, and by the end of the story the would-be kidnappers paid the father a hefty ransom to take back his son so that they could quickly escape from the boy.

The sequence used by O. Henry, ex-convict and expert storyteller, was 3, 2, 1, 4. Is that the order you chose? How did you know the correct sequence for these sentences?

and even textbooks (Di Eugenio, 2003). Just as grammatical sentences are structured according to systematic syntactical rules, passages of discourse are structured systematically (see *Investigating Cognitive Psychology: Discourse*).

By adulthood, most of us have a firm grasp of how sentences are sequenced into a greater whole (discourse structure). From our knowledge of discourse structure, we can derive meanings of sentence elements that are not apparent by looking at isolated sentences. To see how sentences influence the interpretation of other sentences, try the exercise in the *Investigating Cognitive Psychology: Deciphering Text* box.

INVESTIGATING COGNITIVE PSYCHOLOGY

Deciphering Text

Rita gave Thomas a book about problem solving. He thanked her for the book. She asked, "Is it what you wanted?" He answered enthusiastically, "Yes, definitely." Rita asked, "Should I get you the companion volume on decision making?" He responded, "Please do."

In the second and third sentences, who were the people and things being referred to with the pronouns "He," "her," "She," and "it"? Why was the noun "book" preceded by the article "a" in the first sentence and by the article "the" in the second one? How do you know what Thomas's answer, "Yes, definitely," means? What is the action being requested in the response, "Please do"?

Cognitive psycholinguists who analyze discourse particularly are intrigued by how we are able to answer the questions posed in the preceding example. When grasping the meanings of pronouns (e.g., *he, she, him, her, it, they, them, we, us*), how do we know to whom (or to what) the pronouns are pointing? How do we know the meanings of what could seem like cryptic utterances (e.g., "Yes, definitely")? What does the use of the definite article *the* (as opposed to the indefinite article *a*) signify to listeners regarding whether a noun was mentioned previously? How do you know what event is being referenced by the verb *do?* The meanings of pronouns, ellipses, definite articles, event references, and other local elements within sentences usually depend on the discourse structure within which these elements appear (Grosz, Pollack, & Sidner, 1989).

To understand discourse, we often rely not only on our knowledge of discourse structure but also on our knowledge of a broad physical, social, or cultural context within which the discourse is presented (Cook & Gueraud, 2005; van Dijk, 2006). Our understanding of the meaning of a paragraph is influenced by our existing knowledge and expectations. For example, this cognitive psychology textbook will be easier to read if you have taken an introductory psychology course than if you have not taken such a course. When reading the sentences in the *Investigating Cognitive Psychology*: *Effects of Expectations in Reading* box, pause between sentences and think about what you know and what you expect, based on your knowledge.

INVESTIGATING COGNITIVE PSYCHOLOGY

Effects of Expectations in Reading

1. Susan became increasingly anxious as she prepared for the upcoming science exam. (What do you know about Susan?)
2. She had never written an exam before, and she wasn't sure how to construct an appropriate test of the students' knowledge. (How have your beliefs about Susan changed?)
3. She was particularly annoyed that the principal had even asked her to write the exam.
4. Even during a teachers' strike, a school nurse should not be expected to take on the task of writing an examination. (How did your expectations change over the course of the four sentences?)

In the preceding example, your understanding at each point in the discourse was influenced by your existing knowledge and expectations based on your own experiences within a particular context. Thus, just as prior experience and knowledge may aid us in lexical processing of text, so may they also aid us in comprehending the text itself. What are the main reading-comprehension processes? The process of reading comprehension is so complex that many entire courses and myriad volumes are devoted exclusively to the topic, but we focus here on just a few processes. These include semantic encoding, acquiring vocabulary, comprehending ideas in text, creating mental models of text, and comprehending text based on context and point of view.

The next sections explore in more detail how we comprehend larger units of language, like essays. We discuss how we retrieve known words from memory and how we infer the meaning of new words. We explore how we understand ideas communicated in text and how our interpretation depends on our point of view. Finally, we consider how we can represent text in mental models.

Comprehending Known Words: Retrieving Word Meaning from Memory

Semantic encoding is the process by which we translate sensory information (i.e., the written words we see) into a meaningful representation. This representation is based on our understanding of the meanings of words. In lexical access, we identify words based on letter combinations. We thereby activate our memory in regard to the words. In semantic encoding, we take the next step and gain access to the meaning of the word

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stored in memory. Sometimes we cannot semantically encode the word because its meaning does not already exist in memory. We then must find another way in which to derive the meanings of words, such as from noting the context in which we read them.

To engage in semantic encoding, the reader needs to know what a given word means. Knowledge of word meanings (vocabulary) closely relates to the ability to comprehend text. People who are knowledgeable about word meanings tend to be good readers and vice versa. A reason for this relationship appears to be that readers simply cannot understand text well unless they know the meanings of the component words. For example, in one study, recall of the semantic content of a passage was much better when participants had a greater relevant vocabulary (Beck, Perfetti, & McKeown, 1982). In children, vocabulary size is positively related to performance on a number of semantic-understanding tasks, including retelling (both written and oral), decoding ability, and the ability to draw inferences across sentences (Hagtvet, 2003). A number of studies suggest that to grasp meaning of a sample of text with ease, one should know approximately 95% of the vocabulary (Nation, 2001; Read, 2000). Still other studies suggest that, for one to enjoy reading a text, one needs to understand about 98% of the vocabulary (Hu & Nation, 2000).

People with larger vocabularies are able to access lexical information more rapidly than are those with smaller vocabularies (Hunt, 1978). Verbal information often is presented rapidly—whether in listening or in reading. The individual who can gain access to lexical information rapidly is able to process more information per unit of time than can one who can only gain access to such information slowly.

Comprehending Unknown Words: Deriving Word Meanings from Context

Another way in which having a larger vocabulary contributes to text comprehension is through learning from context. Whenever we cannot semantically encode a word because its meaning is not already stored in memory, we must engage in some kind of strategy to derive meaning from the text. In general, we must either search for a meaning, using external resources, such as dictionaries or teachers, or formulate a meaning. Using context cues, we formulate the meaning based on the existing information stored in memory.

People learn most of their vocabulary indirectly. They do so not by using external resources but by figuring out the meanings of the flidges from the surrounding information (Werner & Kaplan, 1952).

For example, if you tried to look up the word *fludges* in the dictionary, you did not find it there. From the structure of the sentence you probably figured out that *fludges* is a noun. From the surrounding context you probably figured out that it is a noun having something to do with words or vocabulary. In fact, *fludges* is a nonsense word we used as a placeholder for the word *words* to show how you would gain a fairly good idea of a word's meaning from its context.

One study found that the ability to figure out meanings of words from context was impaired in children with low reading comprehension. If those children had good vocabularies, however, direct instruction could help them learn the meanings of new words just as well as did children with high reading comprehension (Cain, Oakhill, & Lemmon, 2004).

What happens when adults have to learn word meanings from sentence contexts? Studies have found that people with large or small vocabularies (high verbal or low verbal) learn word meanings differently. High-verbal participants perform a deeper analysis of the possibilities for a new word's meaning than do low-verbal participants.

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In particular, the high-verbal participants used a well-formulated strategy for figuring out word meanings. The low-verbal participants seemed to have no clear strategy at all (van Daalen-Kapteijns & Elshout-Mohr, 1981; see also Sternberg & Powell, 1983).

Comprehending Ideas: Propositional Representations

What factors influence our comprehension of what we read? Walter Kintsch has developed a model of text comprehension based on his observations (Kintsch, 1990, 2007; Kintsch & van Dijk, 1978). According to the model, as we read, we try to hold as much information as possible in working memory to understand what we read. We do not try, however, to store the exact words we read in working memory. Rather, we try to extract the fundamental ideas from groups of words. We then store those fundamental ideas in a simplified representational form in working memory.

The representational form for these fundamental ideas is the proposition. Propositions were defined in more detail in Chapter 7. For now, it suffices to say that a proposition is the briefest unit of language that can be independently found to be true or false. For example, the sentence, "Penguins are birds, and penguins can fly" contains two propositions. You can verify independently whether penguins are birds and whether penguins can fly. In general, propositions assert either an action (e.g., flying) or a relationship (e.g., membership of penguins in the category of birds).

According to Kintsch, working memory holds propositions rather than words. Thus, its limits are taxed by large numbers of propositions rather than by any particular number of words (Kintsch & Keenan, 1973). When a string of words in text requires us to hold a large number of propositions in working memory, we have difficulty comprehending the text. When information stays in working memory a longer time, it is better comprehended and better recalled subsequently. Because of the limits of working memory, however, some information must be moved out of working memory to make room for new information.

Propositions that are thematically central to the understanding of the text will remain in working memory longer than propositions that are irrelevant to the theme of the text passage. Kintsch calls the thematically crucial propositions *macropropositions*. He further calls the overarching thematic structure of a passage of text the *macrostructure*. In an experiment testing his model, Kintsch and an associate asked participants to read a 1,300-word text passage (Kintsch & van Dijk, 1978). The participants then had to summarize the key propositions in the passage immediately, at one month, or at three months after reading the passage. What happened after three months? Participants recalled the macropropositions and the overall macrostructure of the passage about as well as could participants who summarized it immediately after reading it. However, the propositions providing nonthematic details about the passage were not recalled as well after one month and not at all well after three months.

Comprehending Text Based on Context and Point of View

What we remember from a given passage of text often depends on our point of view. For example, suppose that you were reading a text passage about the home of a wealthy family. It described many of the features of the house, such as a leaky roof, a fireplace, and a musty basement. It also described the contents of the house, such as valuable coins, silverware, and television sets. How might your encoding and comprehension of the text be different if you were reading it from the point of view of a prospective

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purchaser of the home as opposed to the viewpoint of a prospective cat burglar? In a study using just such a passage, people who read the passage from the viewpoint of a cat burglar remembered far more about the contents of the home. In contrast, those who read from the viewpoint of a homebuyer remembered more about the condition of the house (Anderson & Pichert, 1978). In fact, varying the retrieval situations or cues can cause different details to be remembered. Researchers found that differing retrieval instructions did not affect accuracy but did affect the specific details recalled (Gilbert & Fisher, 2006).

INVESTIGATING COGNITIVE PSYCHOLOGY

Using Redundancy to Decipher Cryptic Text

Read the following passage:

> Aoccdrnig to a rseearch at an Elingsh uinervtisy, it dseon't mttaer in waht oredr the ltteers in a wrod are; the olny iprmoatnt tihng is that the frist and lsat ltteres are at the rghit pclae. The rset can be a toatl mses and you can sitll raed it wouthit porbelm. Tihs is bcuseae we do not raed ervey lteter by itslef but the wrod as a wlohe.

Although most people cannot read the above passage as quickly as they can if all the letters are in the right order, they still can understand what the passage says.

Representing Text in Mental Models

Once words are semantically encoded or their meaning is derived from the use of context, the reader still must create a mental model of the text that is being read. This mental model simulates what is going on in the world (Craik, 1943; see Johnson-Laird, 1989, 2010). A mental model may be viewed as a sort of internal working model of the situation described in the text, as the reader understands it. In other words, the reader creates some sort of mental representation that contains the main elements of the text. These elements are represented in a way that is relatively easy to grasp or at least that is simpler and more concrete than the text itself. For example, suppose that you read the sentence, "The loud bang scared Alice." You may form a picture of Alice becoming scared on hearing a loud noise. Or you may access propositions stored in memory regarding the effects of loud bangs.

A given passage of text or even a given set of propositions (to refer back to Kintsch's model) may lead to more than one mental model (Johnson-Laird, 1983). In fact, you may need to modify your mental model. Whether you do so depends on whether the next sentence is, "She tried to steer off the highway without losing control of the car," or "She ducked to avoid being shot." In representing the loud bang that scared Alice, more than one mental model is possible. If you start out with a different model than the one required in a given passage, your ability to comprehend the text depends on your ability to form a new mental model. You can hold in mind only a limited number of mental models at any given time (Johnson-Laird, Byrne, & Schaeken, 1992). Therefore, when one of the models is incorrect, it must be rejected to make room for new models.

To form mental models, you must make at least tentative inferences (preliminary conclusions or judgments) about what is meant but not said. In the first case, you are likely to assume that a tire blew out. In the second case, you may infer that someone is

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shooting a gun. Note that neither of these things is stated explicitly. The construction of mental models illustrates that, in addition to comprehending the words themselves, we also need to understand how words combine into meaningfully integrated representations of narratives or expositions. Passages of text that lead unambiguously to a single mental model are easier to comprehend than are passages that may lead to multiple mental models (Johnson-Laird, 1989).

Inferences can be of different kinds. One of the most important kinds is a bridging inference (Haviland & Clark, 1974; McNamara et al., 2006). This is an inference a reader or listener makes when a sentence seems not to follow directly from the sentence preceding it. In essence, what is new in the second sentence goes one step too far beyond what is given in the previous sentences. Consider, for example, two pairs of two sentences:

1. John took the picnic out of the trunk. The beer was warm.
2. John took the beer out of the trunk. The beer was warm.

Readers took about 180 milliseconds longer to read the first pair of sentences than the second. Haviland and Clark suggested a reason for this greater processing time. It was that, in the first pair, information needed to be inferred (the picnic included beer) that was directly stated in the second pair.

Zwaan and Pecher (2012) have suggested that when we read text, we create a simulation that recreates what we read in our mind. For example, when subjects read about an eagle sitting in its nest and then had to judge whether images presented afterward showed the object of the sentence, they were faster in their judgments when they saw a sitting eagle than a flying eagle in the image (Zwaan, Stanfield, & Yaxley, 2002).

Although most researchers emphasize the importance of inference making in reading and forms of language comprehension (e.g., Graesser & Kreuz, 1993; Cain & Oakhill, 2007), not all researchers agree. According to the minimalist hypothesis, readers make inferences based only on information that is easily available to them. They do so only when they need to make such inferences to make sense of adjoining sentences (McKoon & Ratcliff, 1992a; Ratcliff & McKoon, 2008). We believe that the bulk of the evidence regarding the minimalist position indicates that it is itself too minimalist. Readers appear to make more inferences than this position suggests (Suh & Trabasso, 1993; Trabasso & Suh, 1993).

To summarize, our comprehension of what we read depends on several abilities. First is gaining access to the meanings of words, either from memory or on the basis of context. Second is deriving meaning from the key ideas in what we read. Third is extracting the key information from the text, based on the contexts surrounding what we read and on the ways in which we intend to use what we read. And fourth is forming mental models that simulate the situations about which we read.

CONCEPT CHECK

1. What is discourse?
2. What technique can you apply when you come across a word you don't know in a text?
3. Does readers' point of view influence their text comprehension?
4. Is there a limit to the number or complexity of mental models one can have about a given text?

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Key Themes

This chapter deals with a number of the major themes reviewed in Chapter 1.

Rationalism versus empiricism. Most psychologists emphasize empirical techniques in their research. But linguists such as Chomsky have emphasized more rationalistic techniques. They analyze language, typically without formally collecting empirical data at all, at least in the cognitive psychologists' sense of what constitutes such data. The stunning insights of Chomsky show that the two methods complement each other. Many insights can evolve from rationalism. They then can be tested by empirical methods.

Domain generality versus domain specificity. In particular, to what extent is language special? Is it a domain apart from other domains, or simply one more cognitive domain like any other? Many psychologists believe that, indeed, something is special about language. At the same time, cognitive processes operate on it so that people use their language in practically all the other domains in which they work. For example, many mathematical and physical problems are presented with words.

SUMMARY

1. **What properties characterize language?** There are at least six properties of language, defined as the use of an organized means of combining words to communicate: (a) Language permits us to communicate with one or more people who share our language. (b) Language creates an arbitrary relationship between a symbol and its referent—an idea, a thing, a process, a relationship, or a description. (c) Language has a regular structure; only particular sequences of symbols (sounds and words) have meaning. Different sequences yield different meanings. (d) The structure of language can be analyzed at multiple levels (e.g., phonemic and morphemic). (e) Despite having the limits of a structure, language users can produce novel utterances; the possibilities for generating new utterances are virtually limitless. (f) Languages constantly evolve.

   Language involves verbal comprehension—the ability to comprehend written and spoken linguistic input, such as words, sentences, and paragraphs. It also involves verbal fluency—the ability to produce linguistic output. The smallest units of sound produced by the human vocal tract are phonemes. Phonemes are the smallest units of sound that can be used to differentiate meaning in a given language. The smallest semantically meaningful unit in a language is a morpheme. Morphemes may be either roots or affixes—prefixes or suffixes. A lexicon is the repertoire of morphemes in a given language (or for a given language user). The study of the meaningful sequencing of words within phrases and sentences in a given language is syntax. Larger units of language are embraced by the study of discourse.
2. **What are some of the processes involved in language?** In speech perception, listeners must overcome the influence of coarticulation (overlapping) of phonemes on the acoustic structure of the speech signal. Categorical perception is the phenomenon in which listeners perceive continuously varying speech sounds as distinct categories. It lends support to the notion that speech is perceived via specialized processes. Those who believe speech perception is

ordinary explain speech perception in terms of feature-detection, prototype, and Gestalt theories of perception.

Syntax is the study of the linguistic structure of sentences. Phrase-structure grammar analyzes sentences in terms of the hierarchical relationships among words in phrases and sentences.

Transformational grammar analyzes sentences in terms of transformational rules that describe interrelationships among the structures of various sentences. Some linguists have suggested a mechanism for linking syntax to semantics. By this mechanism, grammatical sentences contain particular slots for syntactical categories. These slots may be filled by words that have particular thematic roles within the sentences. According to this view, each item in a lexicon contains information regarding appropriate thematic roles, as well as appropriate syntactical categories.

3. **How do perceptual processes interact with the cognitive processes of reading?** The reading difficulties of people with dyslexia often relate to problems with the perceptual aspects of reading.

   Reading includes two basic kinds of processes: (a) lexical processes, which include sequences of eye fixations and lexical access; and (b) comprehension processes.
4. **How does discourse help us understand individual words?** Obviously, we can understand discourse only through analysis of words. But sometimes we understand words through discourse. For one example, sometimes in a conversation or watching a movie, we miss a word. The context of the discourse helps us figure out what the word was likely to be. As a second example, sometimes a word can have several meanings, such as "well." We use discourse to help us figure out which meaning is intended. As a third example, sometimes we realize, through discourse, that a word is intended to mean something different from its actual meaning, as in "Yeah, right!" Here, "right" is likely to be intended to mean "not really right at all." So discourse helps us understand individual words, just as the individual words help us understand discourse.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe the six key properties of language.
2. In your opinion, why do some view speech perception to be special, whereas others consider speech perception to be ordinary?
3. Compare and contrast the speech-is-ordinary and speech-is-special views, particularly in reference to categorical perception and phonemic restoration.
4. How do phrase-structure diagrams reveal the alternative meanings of ambiguous sentences?
5. Write a noun phrase and a verb phrase. How are they different?
6. In this chapter, we saw that passive-voice sentences can be transformed into active-voice sentences using transformation rules. What are some other kinds of sentence structures that are related to one another? In your own words, state the transformation rules that would govern the changes from one form to another.

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7. On the basis of the discussion of reading in this chapter, what practical suggestion could you recommend that might make reading easier for someone who is having difficulty reading?

KEY TERMS

categorical perception, p. 338
coarticulation, p. 336
communication, p. 331
comprehension processes, p. 352
connotation, p. 341
deep structure, p. 348
denotation, p. 341
discourse, p. 356
dyslexia, p. 356
function morphemes, p. 345
grammar, p. 343
language, p. 330
lexical access, p. 353
lexical processes, p. 352
lexicon, p. 335
morpheme, p. 335
noun phrase, p. 335
phoneme, p. 334
phonemic-restoration effect, p. 337
phrase-structure grammar, p. 345
psycholinguistics, p. 331
referent, p. 332
semantics, p. 341
surface structure, p. 348
syntax, p. 335
thematic roles, p. 350
transformational grammar, p. 348
verb phrase, p. 335
word-superiority effect, p. 354

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 39—Categorical Perception, Identification
Lab 40—Categorical Perception, Discrimination
Lab 15—Suffix Effect
Lab 42—Lexical Decision
Lab 44—Word Superiority

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10

Language in Context

CHAPTER OUTLINE

Language and Thought
- Differences among Languages
  - The Sapir–Whorf Hypothesis
  - Linguistic Relativity or Linguistic Universals?
- Bilingualism and Dialects
  - Bilingualism—An Advantage or Disadvantage?
  - Factors That Influence Second-Language Acquisition
  - Bilingualism: One System or Two?
  - Language Mixtures and Change
  - Neuroscience and Bilingualism
- Slips of the Tongue
- Metaphorical Language

Language in a Social Context
- Characteristics of Successful Conversations
- Gender and Language

Do Animals Have Language?

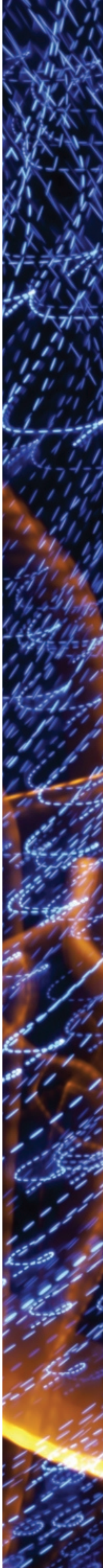
Neuropsychology of Language
- Brain Structures Involved in Language
  - The Brain and Word Recognition
  - The Brain and Semantic Processing
  - The Plasticity of the Brain
  - The Brain and Sex Differences in Language Processing
  - The Brain and Sign Language
- Aphasia
  - Wernicke's Aphasia
  - Broca's Aphasia
  - Global Aphasia
  - Anomic Aphasia
- Autism

Key Themes

Summary

Thinking about Thinking: Analytical, Creative, and Practical Questions

Key Terms



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Here are some of the questions we will explore in this chapter:

1. How does language affect the way we think?
2. How does our social context influence our use of language?
3. How can we find out about language by studying the human brain, and what do such studies reveal?

BELIEVE IT OR NOT | Is It Possible to Count without Words for Numbers?

Not all cultures in the world have developed words for numbers. Even if they do have counting systems and words for numbers, those systems and words may be quite different. The Piraha tribe, which lives along the banks of the Amazon River in Brazil, has just three number words—one for the number 1, one for the number 2, and one that indicates "many." Does this lack of number words interfere with people's ability to deal with larger numerical quantities? Peter Gordon conducted experiments with members of the Piraha tribe and found that, indeed, it does. He presented members of the tribe with matching tasks in which he lined up specific numbers of batteries and asked them to line up an equal amount. Although the Piraha were able to complete this task well for numbers of up to three, their performance declined as the numbers increased. This finding may indicate that we do not have an innate ability to count beyond small numbers. A lack of words for larger numbers may prevent people from thinking about those larger quantities (Gordon, 2004). In this chapter, we explore how people use language in a social context, and how the environment influences people's language and cognition.

> "My surgeon was a butcher."
>
> "His house is a rat's nest."
>
> "Her sermons are sleeping pills."
>
> "He's a real toad, and he always dates real dogs."
>
> "Abused children are walking time bombs."
>
> "My boss is a tiger in board meetings but a real pussycat with me."
>
> "Billboards are warts on the landscape."
>
> "My cousin is a vegetable."
>
> "John's last girlfriend chewed him up and spit him out."

Not one of the preceding statements is literally true. Yet fluent readers of English have little difficulty comprehending these metaphors and other nonliteral forms of language. How do we comprehend them? One of the reasons that we can understand nonliteral uses of language is that we can interpret the words we hear within a broader linguistic, cultural, social, and cognitive context.

In this chapter, we first focus on the cognitive context of language—we look at how language and thought interact. Next, we discuss some uses of language in its social context. Then we explore animal language because it puts human language in perspective.

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Finally, we examine some neuropsychological insights into language. Although the topics in this chapter are diverse, they all have one element in common: They address the issue of how we use language in everyday contexts to communicate with others and to make our communications as meaningful as we possibly can.

Language and Thought

One of the most interesting areas in the study of language is the relationship between language and thinking (Harris, 2003). Many people believe that language shapes thoughts. It is for this reason that the *Publication Manual of the American Psychological Association* emphasizes precise language in researchers' writings. For this reason politicians and media use labels such as "freedom fighters" versus "terrorists" or "surgical strikes" versus "bombing raids."

Many different questions have been asked about the relationship between language and thought. We consider only some of them here. Studies comparing and contrasting users of differing languages and dialects form the basis of this section.

Differences among Languages

Why are so many different languages spoken around the world? And how does using any language in general and using a particular language influence human thought? As you know, different languages comprise different lexicons and use different syntactical structures. These differences often reflect variations in the physical and cultural environments in which the languages arose and developed. For example, in terms of lexicon, the Garo of Burma distinguish among many kinds of rice, which is understandable because they are a rice-growing culture. Nomadic Arabs have more than 20 words for camels. These peoples clearly conceptualize rice and camels more specifically and in more complex ways than do people outside their cultural groups. As a result of these linguistic differences, do the Garo think about rice differently than we do? And do the Arabs think about camels differently than we do? Consider the way we discuss computers. We differentiate between many aspects of computers, including whether the computer is a desktop or a laptop, is a PC or a Mac, or uses Linux or Windows as an operating system. A person from a culture that does not have access to computers would not require so many words or distinctions to describe these machines. We expect, however, specific performance and features for a given computer based on these distinctions. Clearly, we think about computers in a way that is different than that of people who have never encountered a computer.

The syntactical structures of languages differ, too. Almost all languages include ways to communicate actions, agents of actions, and objects of actions (Gerrig & Banaji, 1994). What differs across languages is the order of subject, verb, and object in a typical declarative sentence. The range of grammatical inflections and other markings that speakers are obliged to include as key elements of a sentence is also different across languages. For example, in describing past actions in English, we indicate whether an action took place in the past by changing (inflecting) the verb form. For example, *walk* changes to *walked* in the past tense. In Spanish and German, the verb also must indicate whether the agent of action was singular or plural and whether it is being referred to in the first, second, or third person. In Turkish, the verb form also must indicate whether the action was witnessed or experienced directly by the speaker or was noted only indirectly. Do these differences and other differences in obligatory syntactical structures influence—or even constrain—the users of these languages to think about things differently because of the language they use while thinking? We will have a closer look at these questions in the next two sections, in which we explore the concepts of linguistic relativity and linguistic universals.

Linguistic Relativity: The Sapir–Whorf Hypothesis

Does language influence thinking? The **linguistic relativity** hypothesis suggests it does. Speakers of different languages have somewhat differing cognitive systems. These different cognitive systems influence the ways people think about the world. Thus, according to the relativity view, the Garo would think about rice differently—perhaps with greater complexity of thought—than English speakers, who have only a few words for rice. Thus, language would shape thought. Word learning may occur partly as a result of infants' mental differentiations among various kinds of concepts (Carey, 1994; Xu & Carey, 1995, 1996). So it might make sense that infants who encounter different kinds of objects might make different kinds of mental differentiations. These differentiations would be a function of the culture in which the infants grew up.

The linguistic-relativity hypothesis is sometimes referred to as the *Sapir–Whorf hypothesis*, named after the two men who were most forceful in propagating it. Edward Sapir (1941/1964) said that "we see and hear and otherwise experience very largely as we do because the language habits of our community predispose certain choices of interpretation" (p. 69). Benjamin Lee Whorf (1956) stated this view even more strongly:

> *We dissect nature along lines laid down by our native languages. The categories and types that we isolate from the world of phenomena we do not find there because they stare every observer in the face; on the contrary, the world is presented in a kaleidoscopic flux of impressions which has to be organized by our minds—and this means largely by the linguistic systems in our minds. (p. 213)*

The Sapir–Whorf hypothesis has been one of the most widely discussed ideas in the social and behavioral sciences (Lonner, 1989).

Consider a milder form of linguistic relativism: Language may not determine thought, but language may influence thought. Our thoughts and our language interact in myriad ways, only some of which we now understand. Clearly, language facilitates thought; it even affects perception and memory. For some reason, we have limited means by which to manipulate nonlinguistic images (Hunt & Banaji, 1988). Such limitations make desirable the use of language to facilitate mental representation and manipulation. Even nonsense pictures ("droodles") are recalled and redrawn differently, depending on the verbal label given to the picture (Bower, Karlin, & Dueck, 1975).

To see how this phenomenon might work, look at Figure 10.1 ■. Once a particular label has been given to a figure, viewing the same figure from the alternative perspective is much harder (Glucksberg, 1988). Psychologists have used other ambiguous figures (see Chapters 4 and 7) and have found similar results. When participants are given a particular label, they tend to draw their recollection of the figure in a way more similar to the given label. For example, after viewing a figure of two circles connected by a single line, they will draw a figure differently as a function of whether it is labeled "eyeglasses" or "dumbbells." Specifically, the connecting line will either be lengthened or shortened, depending on the label.

Language also affects how we encode, store, and retrieve information in memory. Remember the examples in Chapter 6 regarding the label "Washing Clothes"? That label enhanced people's responses to recall and comprehension questions about text passages (Bransford & Johnson, 1972, 1973). In a similar vein, eyewitness testimony is powerfully influenced by the distinctive phrasing of questions posed to the eyewitnesses (Loftus & Palmer, 1974; see also Chapter 6 for more information on eyewitness testimony). In a

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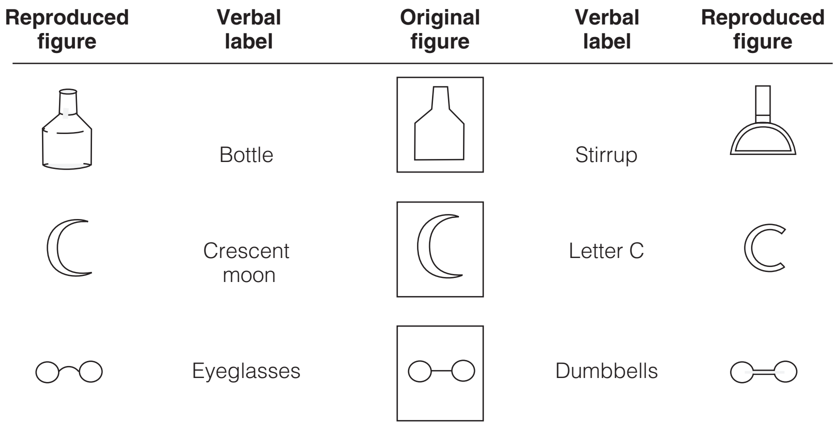

Figure 10.1 Labels Affect Perception When the original figures (in the center) are redrawn from memory, the new drawings tend to be distorted to be more like the labeled figures.

Source: Based on *Psychology*, Fifth Edition, by John Darley, et al. Copyright © 1998, Pearson Education.

famous study, participants viewed an accident (Loftus & Palmer, 1974). Participants then were asked to describe the speeds of the cars before the accident. The word indicating impact was varied across participants. These words included *smashed, collided, bumped,* and *hit.* When the word *smashed* was used, the participants rated speed as significantly higher than when any of the other words were used. The connotation of the word *smash* thereby seems to bias participants to estimate a higher speed. Similarly, when participants were asked whether they saw broken glass (after a week's delay), the participants who were questioned with the word *smashed* said "yes" much more frequently than did any of the other participants (Loftus & Palmer, 1974).

Even when participants generated their own descriptions, the subsequent accuracy of their eyewitness testimony declined (Schooler & Engstler-Schooler, 1990). Accurate recall actually declined following an opportunity to write a description of an observed event, a particular color, or a particular face. This phenomenon has been called the "verbal overshadowing effect." When given an opportunity to identify statements about an event—the actual color or a face—participants were less able to do so accurately if they previously had described it. If participants described the event or person but then had to work on another task, the verbal overshadowing effect was less pronounced than when they identified a person or object right after describing the one or the other (Alogna et al., 2014). Paradoxically, when participants were allowed to take their time in responding, their performance was even less accurate than when they were forced to respond quickly. In other words, given time to reflect on their answers, participants were more likely to respond in accord with what they had said or written than with what they had seen.

The particular language also influences how much he or she remembers about incidents. One study showed Spanish-speaking and English-speaking participants videos in which objects like balloons or cans were broken, either accidentally or on purpose. They then described what they had seen. When objects were unintentionally broken, English speakers often used agentive language ("he crushed the can"), whereas Spanish speakers more often used nonagentive language ("the can was crushed"). Language did not influence participants' memory for those instances in which something had been broken intentionally, but when something had been broken by accident, English speakers remembered agents better than Spanish speakers (Fausey & Boroditsky, 2011).

Linguistic Relativity versus Linguistic Universals

Some research has addressed **linguistic universals**—characteristic patterns across all languages of various cultures—and relativity. Recall from Chapter 9 that linguists have identified hundreds of linguistic universals related to phonology (the study of

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phonemes), morphology (the study of morphemes), semantics, and syntax. For example, Chomsky would argue that deep structure applies, in its own way, to the syntaxes of all languages.

Colors An area that illustrates much of this research focuses on color names. These words provide an especially convenient way of testing for universals. Why? Because people in every culture can be expected to be exposed, at least potentially, to pretty much the same range of colors.

In actuality, different languages name colors quite differently. But the languages do not divide the color spectrum arbitrarily. A systematic pattern seems universally to govern color naming across languages. Consider the results of investigations of color terms across a large number of languages (Berlin & Kay, 1969; Kay, 1975). Two apparent linguistic universals about color naming have emerged across languages. First, all the languages surveyed took their basic color terms from a set of just 11 color names. These are *black, white, red, yellow, green, blue, brown, purple, pink, orange,* and *gray.* Languages ranged from using all 11 color names, as in English, to using just two of the names, as in the Dani tribe of Western New Guinea (Rosch Heider, 1972). Second, when only some of the color names are used, the naming of colors falls into a hierarchy of five levels. The levels are (1) black, white; (2) red; (3) yellow, green, blue; (4) brown; and (5) purple, pink, orange, gray. Thus, if a language names only two colors, they will be black and white. If it names three colors, they will be black, white, and red. A fourth color will be taken from the set of yellow, green, and blue. The fifth and sixth will be taken from this set as well. Selection will continue until all 11 colors have been labeled. The order of selection within the categories may, however, vary between cultures (Jameson, 2005).

Another study had participants name various colors that were shown to them on color plates. Participants also were asked to choose the best example for each color (e.g., out of the many color plates presented, which is the best "red"?). This procedure was done for many languages, and the results showed that the "best" colors tended to cluster around the colors that English speakers call red, yellow, green, and blue (Regier, Kay, & Cook, 2005). This result indicates that there are some universals in color perception.

In contrast, several studies have shown that color categories vary, depending on the speaker's language. For example, Berinmo speakers from New Guinea tend to combine the colors we call green and blue under one name—*nol* (Roberson, Davies, & Davidoff, 2000; Roberson et al., 2005). Other languages tend to see categorical differences where English speakers do not see any. For example, Russian speakers consider light blue (*goluboy*) and dark blue (*siniy*) two different colors (Winawer et al., 2007). Various theories have been proposed of why color names differ in different cultures. It has been proposed, for example, that the sun's ultraviolet rays causes people's lenses to yellow, which makes it harder to discriminate between green and blue. The large sun exposure, then, in areas near the equator could explain the relative scarcity of separate color terms for blue and green in some languages in this area (Lindsey & Brown, 2002). It also could be that color names are an evolutionary result of the most frequently occurring colors in the environment of members of a particular language group (Yendrikhovskij, 2001). But so far, none of the theories are consistent with each other.

Overall, although it seems that color naming is relatively universal in that it clusters worldwide around the same areas, color categories vary considerably and color names can affect perception and cognition (Kay & Regier, 2006; Roberson & Hanley, 2007).

BELIEVE IT OR NOT **Do You See Colors to Your Left Differently Than Colors To Your Right?**

The language center of the brain is located mostly in the left hemisphere. At the same time, light from objects on our right falls onto the left side of our retina and then is transmitted to the left hemisphere of the brain (and vice versa; for an illustration of this, see Figure 2.8 in Chapter 2). Could this circumstance influence our perception of colors? Participants were shown a circle consisting of colored green squares. One of those squares was of a different color—either blue or a different shade of green—and it was located either in the lower right or lower left of the circle. The time it took people to pick the square with the different color was measured. If the square was located on the left (and the light therefore was transmitted to the right hemisphere), it did not make a difference whether its color was blue or a different shade of green. If the square was on the right, the blue square was detected faster than the green square. This is because the language center in the left hemisphere interacted with color recognition. If participants' language centers were kept busy with a memory task, the effect disappeared, making it indeed likely that the effect was a result of language (Gilbert et al., 2006).

Verbs and Grammatical Gender Syntactical as well as semantic structural differences across languages may affect thought. For example, Spanish has two forms of the verb "to be"—*ser* and *estar.* However, they are used in different contexts. One investigator studied the uses of *ser* and *estar* in adults and in children (Sera, 1992).

When "to be" indicated the identity of something (e.g., in English, "This is José.") or the class membership of something (e.g., "José is a carpenter."), both adults and children used the verb form *ser.* When "to be" indicated attributes of things, both adults and children used *ser* to indicate permanent attributes (e.g., "Maria is tall.") and used *estar* to indicate temporary attributes (e.g., "Maria is busy."). Finally, when using forms of "to be" to describe the locations of objects, including people, animals, and other things, both adults and children used *estar* (e.g., "Marie is on the chair."). However, when using forms of "to be" to describe the locations of events (e.g., meetings or parties), adults used *ser,* whereas children continued to use *estar.*

Children treat the location of events in the same way as the location of objects. They view it as temporary and hence use *estar.* Adults, in contrast, differentiate between events and objects. In particular, adults consider the locations of events to be unchanging. Because they are permanent, they require the use of *ser.*

Sera's work suggests that differences in language use may indeed indicate differences in thinking. However, her work leaves open an important psychological question: Do native Spanish speakers have a more differentiated sense of the temporary and the permanent than do native English speakers, who use the same verb form to express both senses of "to be"? The answer is unclear.

Other languages also have been used in investigations of linguistic relativity. Some studies explore the relevance of different languages using different prepositions. In English, people use the prepositions "in" and "on" to describe putting a pear in a bowl or putting a cup on the table. "In" refers to containment of some sort, whereas "on" refers to support. Korean speakers differentiate between "tight fit" (*kkita*, like a DVD in its sleeve) and "loose fit" (*nehta,* like a pear in a bowl) in their prepositions. In one experiment, participants were shown several spatial actions and had to pick the one that seemed "odd" and not to fit the other actions. The spatial actions were performed with objects of different texture and material (e.g., wooden or made of sponge) and showed the objects either being put in a tight-fitting setting or a loose container. In all, 80% of the Korean speakers picked the odd scene on the basis of whether or not it involved tight/loose fit. In comparison, only 37% of English speakers did. The majority of English speakers picked out a scene where the material or shape of the object differed (McDonough, Choi, & Mandler, 2003).

Another experiment tested the effect of grammatical gender. The study was conducted in English, but participants were native German and Spanish speakers. They were presented with 24 noun words that they had to describe in three adjectives each. In all, 12 of the nouns were feminine in German and masculine in Spanish, and the other 12 nouns were masculine in German and feminine in Spanish. There were marked differences in how the objects were described, depending on their gender. For example, the word *key*, which is feminine in Spanish (*la llave*), was described by the Spanish speakers as "golden, intricate, little, lovely." In German, the word key is masculine (*der Schluessel*) and was described as "hard, heavy, jagged, metal." The effect is especially impressive because the experiment was conducted in English and did not involve the participants speaking German or Spanish (Boroditsky, Schmidt, & Phillips, 2003). Also consider some additional facts:

- Children who learn Mandarin Chinese tend to use more verbs than nouns. In contrast, children acquiring English or Italian tend to use more nouns than verbs (Tardif, 1996; Tardif, Shatz, & Naigles, 1997).
- Korean-speaking children use verbs earlier than do English-speaking children. In contrast, English-speaking children have larger naming vocabularies earlier than do Korean-speaking children (Gopnik & Choi, 1995; Gopnik, Choi, & Baumberger, 1996).

What differences in thinking might such differences in acquisition imply? No one knows for sure.

Concepts An intriguing experiment assessed the possible effects of linguistic relativity by studying people who speak more than one language (Hoffman, Lau, & Johnson, 1986). In Chinese, a single term, *shì gÈ*, specifically describes a person who is "worldly, experienced, socially skillful, devoted to his or her family, and somewhat reserved" (p. 1098). English clearly has no comparable single term to embrace these diverse characteristics. Hoffman and his colleagues composed text passages in English and in Chinese describing various characters. They included the *shì gÈ* stereotype, without, of course, specifically using the term *shì gÈ* in the descriptions. The researchers then asked participants who were fluent in both Chinese and English to read the passages either in Chinese or in English. Then they rated various statements about the characters, in terms of the likelihood that the statements would be true of the characters. Some of these statements involved a stereotype of a *shì gÈ* person.

Their results seemed to support the notion of linguistic relativity. The participants were more likely to rate the various statements in accord with the *shì gÈ* stereotype when they had read the passages in Chinese than when they had read the passages in English. Similarly, when participants were asked to write their own impressions of the characters, their descriptions conformed more closely to the *shì gÈ* stereotype if they previously read the passages in Chinese. These authors do not suggest that it would be impossible for English speakers to comprehend the *shì gÈ* stereotype. Rather, they suggest that having that stereotype readily accessible facilitates its mental manipulation.

Research on linguistic relativity is a good example of the dialectic in action. Before Sapir and Whorf, the issue of how language constrains thought was not at the forefront in psychology. Sapir and Whorf then presented a thesis that language largely controls thought. Subsequently, a number of psychologists tried to show the antithesis—that

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language does not control thought. Today, many psychologists believe in a synthesis: Language has some influence on thought but not nearly so extreme an influence as Sapir and Whorf believed. It is probably the case that language and thought interact with each other throughout the life span (Vygotsky, 1986).

in the lab of **KEITH RAYNER**

Eye Movements and Reading

Reading is a remarkable achievement of the human brain/mind. How do we understand written language on a moment-to-moment basis? This is the primary question that has driven my research for many years. We typically use eye movement measures as a reflection of moment-to-moment processing. A considerable amount of research from my lab (and others) clearly documents that how long readers look at words in text is strongly influenced by cognitive processes and the ease or difficulty associated with processing a word. For example, readers look longer at low-frequency words (such as *vituperative*) than high-frequency words (such as *house*).

There are a number of critical issues that needed attention before one could safely assume that eye movements reflect moment-to-moment processing. In reading, our eyes pause on average for about 200 to 250 milliseconds. How much useful information do readers obtain on each fixation? To answer this question, George McConkie and I developed a gaze contingent moving window paradigm in which we controlled how much information readers had available on each fixation. We found that the span of perception in reading extends about 3 to 4 letter spaces to the left of fixation to about 14 to 15 letters spaces to the right of fixation for readers of English.

Courtesy of Keith Rayner

Keith Rayner

In subsequent work, I developed a gaze-contingent boundary paradigm to determine what kind of information readers obtain from the word to the right of fixation. This work documented that readers obtain a preview benefit from having valid information to the right of fixation. In these types of experiments (which are quite popular these days), the type of information that is available in a target word location is manipulated (so, for example, the preview might be the word *chest*), but during the eye movement to the word, the preview changes to the target word (*chart*). The amount of preview benefit depends on how far away the eyes were from the target word when the saccade was launched and the relationship between the preview and the target.

A final type of gaze-contingent technique that we developed is the disappearing-text paradigm. Here, on each fixation, the word the reader is looking at disappears (or is masked) early in a fixation. The first remarkable finding is that readers can read normally if they get to see the fixated word for 50 to 60 milliseconds (this doesn't mean that word recognition is completed in this time, just that the information has been entered into the processing system). Second, how long the eyes remain in place is strongly influenced by the frequency of the fixated word: If it is a low-frequency word, the eyes remain on it longer than if it is a high-frequency word. This is good evidence that cognitive processing drives eye movements during reading.

Given these findings, eye movements can be used to study moment-to-moment processing. In my lab, we have taken advantage of the various types of ambiguity that exist in written English to strive to understand readers' moment-to-moment comprehension processes. Thus, we have studied how readers parse sentences that contain temporary syntactic ambiguities, as well as how they deal with lexically ambiguous words (words with two meanings, such as bank and straw) and phonologically ambiguous words (that are spelled the same but have two different pronunciations). We also have used eye movement data to study higher-level discourse processing, though the link between such processes and how long readers look at parts of the text is much more tenuous than is the case with lexical processes. Finally, given that we have learned so much about the relationship between eye movements and reading, we (Erik Reichle, Sandy Pollatsek, Don Fisher, and myself) developed a model of eye movement control in reading (called the *E-Z Reader model*) that does a good job of predicting where readers fixate and how long they fixate on words.

Note: Sadly, Keith Rayner passed away during the preparation of the current edition of this book.

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Bilingualism and Dialects

Suppose a person can speak and think in two languages. Does the person think differently in each language? And do **bilinguals**—people who can speak two languages—think differently from **monolinguals**—people who can speak only one language? (Multilinguals speak at least two and possibly more languages.) What differences, if any, emanate from the availability of two languages versus just one? Might bilingualism affect intelligence, positively or negatively?

Bilingualism—An Advantage or Disadvantage?

Does bilingualism make thinking in any one language more difficult, or does it enhance thought processes? The data are somewhat contradictory. Different participant populations, different methodologies, different language groups, and different experimenter biases may have contributed to the inconsistency in the literature. Consider what happens when bilinguals are balanced bilinguals, who are roughly equally fluent in both languages, and when they come from middle-class backgrounds. In these instances, positive effects of bilingualism tend to be found. Executive functions, which are located primarily in the prefrontal cortex and include abilities such as to shift between tasks or ignore distracters, are enhanced in bilingual individuals. Even the onset of dementia in bilinguals may be delayed by as much as four years (Andreou & Karapetsas, 2004; Bialystok & Craik, 2010; Heidmayr et al., 2014). A study of immigrant children found that those children who were fluent in two languages (their native language and English) earned more in their first job than those who ended up being fluent only in English or their native language (Agirdag, 2014). Also, bilingual toddlers pay more attention to unexpected stimuli than monolingual toddlers, thus enabling them to process these stimuli more effectively (Kuipers & Thierry, 2013). But negative effects may result as well. Bilingual speakers tend to have smaller vocabularies and their access to lexical items in memory is slower (Bialystok, 2001; Bialystok & Craik, 2010). What might be the causes of this difference?

Let us distinguish between what might be called *additive versus subtractive bilingualism* (Cummins, 1976). In *additive bilingualism,* a second language is acquired in addition to a relatively well-developed first language. In *subtractive bilingualism,* elements of a second language replace elements of the first language. It appears that the additive form results in increased thinking ability. In contrast, the subtractive form results in decreased thinking ability (Cummins, 1976). In particular, there may be something of a threshold effect. Individuals may need to be at a certain relatively high level of competence in both languages for a positive effect of bilingualism. Classroom teachers often discourage bilingualism in children (Sook Lee & Oxelson, 2006), through letters requesting only English be spoken at home, or through subtle attitudes and methods. Additionally, children from backgrounds with lower socioeconomic status (SES) may be more likely to be subtractive bilinguals than are children from the middle SES. Their SES may be a factor in their being hurt rather than helped by their bilingualism.

Researchers also distinguish between *simultaneous bilingualism,* which occurs when a child learns two languages from birth, and *sequential bilingualism,* which occurs when an individual first learns one language and then another (Bhatia & Ritchie, 1999). Either form of language learning can contribute to fluency. It depends on the particular circumstances in which the languages are learned (Pearson et al., 1997). It is known, however, that infants begin babbling at roughly the same age. This happens regardless of whether they consistently are exposed to one or two languages (Oller et al., 1997). In the United States, many people make a big deal of bilingualism, perhaps because relatively few Americans born in the United States of nonimmigrant parents learn a second language to a high degree of fluency. In other cultures, however, the learning of multiple languages is taken for granted. For example, in parts of India, people routinely learn as many as four languages (Khubchandani, 1997). In Flemish-speaking Belgium, many people learn at least some French, English, or German. Often, they learn one or more of these other languages to a high degree of fluency.

Factors That Influence Second-Language Acquisition

A significant factor believed to contribute to acquisition of a language is age. Some researchers have suggested that native-like mastery of some aspects of a second language is rarely acquired after adolescence. Other researchers disagree with this view (Bahrick et al., 1994; Herschensohn, 2007). They found that some aspects of a second language, such as vocabulary comprehension and fluency, seem to be acquired just as well after adolescence as before. Furthermore, these researchers found that even some aspects of syntax seem to be acquired readily after adolescence. These results contradict prior findings. The mastery of native-like pronunciation often seems to depend on early acquisition. But individual differences are great and some learners attain native-like language abilities even at a later age (Birdsong, 2009). It may seem surprising that learning completely novel phonemes in a second language may be easier than learning phonemes that are highly similar to the phonemes of the first language (Flege, 1991). In any case, there do not appear to be critical periods for second-language acquisition (Birdsong, 1999, 2009). Adults may appear to have a harder time learning second languages because they can retain their native language as their dominant language. Young children, in contrast, who typically need to attend school in the new language, may have to switch their dominant language. So, they learn the new language to a higher level of mastery (Jia & Aaronson, 1999). This does not mean that we cannot learn a new language later in life, but rather, that the earlier we learn it, the more likely we will become highly proficient in its use.

What kinds of learning experiences facilitate second-language acquisition? There is no single correct answer to that question (Bialystok & Hakuta, 1994). One reason is that each individual language learner brings distinctive cognitive abilities and knowledge to the language-learning experience. In addition, the kinds of learning experiences that facilitate second-language acquisition should match the context and uses for the second language once it is acquired. For example, consider these individuals:

- Caitlin, a young child, may not need to master a wealth of vocabulary and complex syntax to get along well with other children. If she can master the phonology, some simple syntactical rules, and some basic vocabulary, she may be considered fluent.
- Similarly, José needs only to get by in a few everyday situations, such as shopping, handling routine family business transactions, and getting around town. He may be considered proficient after mastering some simple vocabulary and syntax, as well as some pragmatic knowledge regarding context-appropriate manners of communicating.
- Kim Yee must be able to communicate regarding her specialized technical field. She may be considered proficient if she masters the technical vocabulary, a primitive basic vocabulary, and the rudiments of syntax.
- Sumesh is a student who studies a second language in an academic setting. Sumesh may be expected to have a firm grasp of syntax and a rather broad, if shallow, vocabulary.

Each of these language learners may require different kinds of language experiences to gain the proficiency being sought. Different kinds of experiences may be needed to

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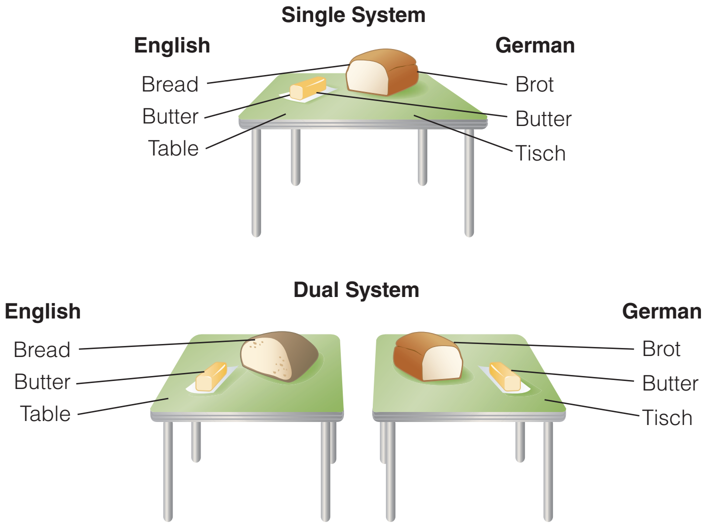
enhance their competence in the phonology, vocabulary, syntax, and pragmatics of the second language.

When speakers of one language learn other languages, they find the languages differentially difficult. For example, it is much easier, on average, for a native speaker of English to acquire Spanish as a second language than it is to acquire Russian. One reason is that English and Spanish share more roots than do English and Russian. Moreover, in Russian, word endings change more often to indicate tense, number, gender, and other grammatical categories than in English and Spanish. English and Spanish are more highly dependent on word order. The difficulty of learning a language as a second language, however, does not appear to have much to do with its difficulty as a first language. Russian infants probably learn Russian about as easily as U.S. infants learn English (Maratsos, 1998).

Bilingualism: One System or Two?

One way to approach the study of bilingualism is to apply what we have learned from cognitive-psychological research to practical concerns regarding how to help with acquisition of a second language. Another approach is to study bilingual individuals to see how bilingualism may offer insight into the human mind. Some cognitive psychologists have been interested in finding out how the two languages are represented in the bilingual's mind. The **single-system hypothesis** suggests that two languages are represented in just one system or brain region (see Hernandez et al., 2001, for evidence supporting this hypothesis in early bilinguals). Alternatively, the **dual-system hypothesis** suggests that two languages are represented somehow in separate systems of the mind (De Houwer, 1995; Paradis, 1981). For instance, might German language information be stored in a physically different part of the brain than English language information? Figure 10.2 ■ shows schematically the difference in the two points of view.

One way to address this question is by studying bilinguals who have experienced brain damage. Suppose a bilingual person has brain damage in a particular part of the brain. According to the dual-system hypothesis, the individual would show different degrees of impairment in the two languages. The single-system view would suggest roughly equal impairment in the two languages. The logic of this kind of investigation is



■ **Figure 10.2 Single-System and Dual-System Hypotheses.** The single-system conceptualization hypothesizes that both languages are represented in a unified cognitive system. The dual-system conceptualization of bilingualism hypothesizes that each language is represented in a separate cognitive system.

compelling, but the results are not. In studies of language recovery after trauma, sometimes the first language recovers first; sometimes the second language recovers first. And sometimes recovery is about equal for the two languages (Albert & Obler, 1978; Marrero, Golden, & Espe Pfeifer, 2002; Paradis, 1977). Recovery of one or both languages seems contingent on age of acquisition of the second language and on preincident language proficiency, among other factors (Marrero, Golden, & Espe Pfeifer, 2002).

A 32-year-old French–German bilingual who suffered from a stroke and subsequent aphasia was trained in German but was given no training in French. The researchers found significant recovery of German, but his German language abilities did not transfer to his French abilities (Meinzer et al., 2007).

The conclusions that can be drawn from all this research are ambiguous. Nevertheless, the results seem to suggest at least some duality of structure. A different method of study has led to an alternative perspective on bilingualism. Two investigators mapped the region of the cerebral cortex relevant to language use in two of their bilingual patients being treated for epilepsy (Ojemann & Whitaker, 1978). Mild electrical stimulation was applied to the cortex of each patient. Electrical stimulation tends to inhibit activity where it is applied. It leads to a reduced ability to name objects for which the memories are stored at the location being stimulated. The results for both patients were the same. They may help explain the contradictions in the literature. Some areas of the brain showed equal impairments for object naming in both languages. But other areas of the brain showed differential impairment in one or the other language. The results also suggested that the weaker language was more diffusely represented across the cortex than was the stronger language. In other words, asking the question of whether two languages are represented singly or separately may be asking the wrong question. The results of this study suggest that some aspects of the two languages may be represented singly; other aspects may be represented separately.

A more recent study (Peltola et al., 2012) suggests that whether one or two systems are used depends on when and how the second language was learned. Balanced bilinguals (generally who learned two languages from birth) showed more interference than dominant bilinguals (generally who learned a second language later on), suggesting that dominant bilinguals may use two linguistic systems, whereas balanced bilinguals may use only one, which potentially leads to interference between the two languages.

To summarize, two languages seem to share some, but not all, aspects of mental representation. Learning a second language is often a plus, but it is probably most useful if the individual learning the second language is in an environment in which the learning of the second language adds to rather than subtracts from the learning of the first language. For beneficial effects to appear, the second language must be learned well. In the approach usually taken in schools, students may receive as little as two or three years of second-language instruction spread out over a few class periods a week. This approach probably will not be sufficient for the beneficial effects of bilingualism to appear. Schooling, however, does seem to yield beneficial effects on acquisition of syntax. This is particularly so when a second language is acquired after adolescence. Furthermore, whenever possible, individual learners should choose specific kinds of language-acquisition techniques that best fit their needs, abilities, preferences, and personal goals for using the second language.

Neuroscience and Bilingualism

Learning a second language increases the gray matter in the left inferior parietal cortex. This density is positively correlated with proficiency. Thus, the more proficient a person is in a second language, the denser this area of the brain will be. Finally, a negative

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correlation exists between age of acquisition and the density in the left inferior parietal cortex (Mechelli et al., 2004; Petitto et al., 2012)—the higher the age of acquisition, the less the density. These findings suggest that this area of the brain benefits from the learning of a second language and that the earlier this learning occurs, the better it is both for brain density and for overall proficiency.

Studies with aphasic patients suggest that first and second languages may be distributed in different anatomic regions of the brain. This assumption comes from the observation of a bilingual patient who suffered a stroke and subsequently had impaired language skills in his native language. His second language, however, was unaffected (Garcia et al., 2010). Other studies, however, suggest that the brain regions activated by two languages actually may overlap (Gandour et al., 2007; Yokohama et al., 2006).

One study examined electrical stimulation via transcranial magnetic stimulation (TMS) of the brains of bilingual speakers. (When stimulation ends, the brain resumes normal functioning.) The researchers found different areas of the brain were active when using the primary versus the secondary language to name items. There was, however, some overlap of active areas for the two languages (Lucas, McKhann, & Ojemann, 2004).

Whether or not the same brain areas are involved likely depends on other factors, like the age of acquisition of the second language.

One study had bilingual people complete a sentence-generation task (i.e., participants were asked to create sentences). The study showed that the centers of activation in the left inferior frontal gyrus are overlapping for early bilinguals. Late bilinguals, however, show separate centers of activation (Kim et al., 1997).

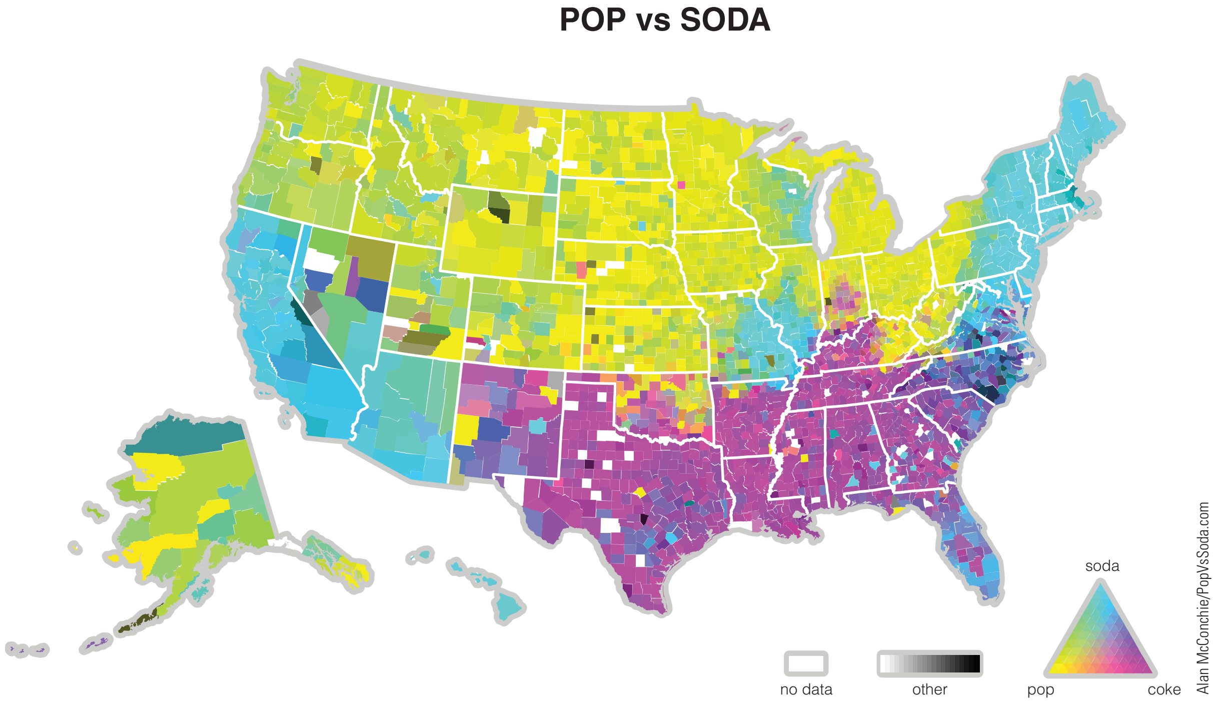
Language Mixtures and Change

Bilingualism is not a certain outcome of linguistic contact between different language groups. Here are some scenarios of what can happen when different language groups come into contact with each other:

- Sometimes when people of two different language groups are in prolonged contact with one another, the language users of the two groups begin to share some vocabulary that is superimposed onto each group's language use. This superimposition results in what is known as a *pidgin*. It is a language that has no native speakers (Wang, 2009).
- Over time, this admixture can develop into a distinct linguistic form. It has its own grammar and hence becomes a *creole*. An example of a creole is the Haitian Creole language, spoken in Haiti. The Haitian Creole language is a combination of French and a number of West African languages.
- Modern creoles may resemble an evolutionarily early form of language, termed *protolanguage* (Bickerton, 1990).

The existence of pidgins and creoles, and possibly a protolanguage, supports the universality notion discussed earlier: Linguistic ability is so natural and universal that, given the opportunity, humans actually invent new languages quite rapidly.

Creoles and pidgins arise when two linguistically distinctive groups meet. A dialect occurs when a single linguistic group gradually diverges toward somewhat distinctive variations. A **dialect** is a regional variety of a language distinguished by features such as vocabulary, syntax, and pronunciation. The study of dialects provides insights into such diverse phenomena as auditory discrimination and social discrimination. Many of the words we choose are a result of the dialect we use. The most well-known example is the word choice for a soft drink. Depending on the dialect you use, you may order a "soda," "pop," or a "Coke" (see Figure 10.3 ■).



Alan McConchie/PopVsSoda.com

Figure 10.3 The Pop versus Soda Controversy. This map shows the distribution of different words used for "soft drink" across the United States. What word people use depends on the dialect they speak.

Dialectical differences often represent harmless regional variations. They create few serious communication difficulties, but these difficulties can lead to some confusion. When call centers route calls to countries outside of the United States, such as India, there may be serious difficulties in achieving effective communication because of differences in dialect as well as accent. Many radio announcers try to learn something close to a standard form of English, often called *network English.* In this way, they can maximize their comprehensibility to as many listeners as possible.

Sometimes, differing dialects are assigned different social statuses, such as *standard* forms having higher status than *nonstandard* ones. The distinction between standard and nonstandard forms of a language can become unfortunate when speakers of one dialect start to view themselves as speakers of a superior dialect. The view that one dialect is superior to another may lead one to make judgments about the speaker that are biased. This *linguicism,* or stereotype based on dialect, may be quite widespread and can cause many interpersonal problems (Zuidema, 2005). For example, we frequently make judgments about people's intelligence, competence, and morality based on the dialect they use. Specifically, a person who uses a nonstandard form may be judged to be less educated or less trustworthy than a person who uses a more standard form. Usually, the standard dialect is that of the class in society that has the most political or economic power. Virtually any thought can be expressed in any dialect.

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Slips of the Tongue

An area of particular interest to cognitive psychologists is how people use language incorrectly. Studying speech errors helps cognitive psychologists better understand normal language processing. One way to use language incorrectly is through **slips of the tongue**—inadvertent linguistic errors in what we say. Slips of the tongue may occur at any level of linguistic analysis: phonemes, morphemes, or larger units of language (Crystal, 1987; McArthur, 1992). In such cases, what we think and what we mean to say do not correspond to what we actually do say. Freudian psychoanalysts have suggested that in the case of Freudian slips, the verbal slips reflect some kind of unconscious processing that has psychological significance. The slips are alleged often to indicate repressed emotions. For example, a business competitor may say, "I'm glad to beat you," when what was overtly intended was, "I'm glad to meet you."

Most cognitive psychologists see things differently from the psychoanalytic view. They are intrigued by slips of the tongue because of what the lack of correspondence between what is thought and what is said may tell us about how language is produced. In speaking, we have a mental plan for what we are going to say. Sometimes, however, this plan is disrupted when our mechanism for speech production does not cooperate with our cognitive one. Often, such errors result from intrusions by other thoughts or by stimuli in the environment, such as background noise from radio talk show or a neighboring conversation (Garrett, 1980; Saito & Baddeley, 2004).

Slips of the tongue may be taken to indicate that the language of thought differs somewhat from the language through which we express our thoughts (Fodor, 1975). Often we have the idea right, but its expression comes out wrong. Sometimes we are not even aware of the slip until it is pointed out to us. In the language of the mind, whatever it may be, the idea is right, although the expression represented by the slip is inadvertently wrong. This fact can be seen in the occasional slips of the tongue even in preplanned and practiced speech (Kawachi, 2002).

People tend to make various kinds of slips in their conversations (Fromkin, 1973; Fromkin & Rodman, 1988):

- In *anticipation*, the speaker uses a language element before it is appropriate in the sentence because it corresponds to an element that will be needed later in the utterance. For example, instead of saying, "an inspiring expression," a speaker might say, "an expiring expression."
- In *perseveration*, the speaker uses a language element that was appropriate earlier in the sentence but that is not appropriate later on. For example, a speaker might say, "We sat down to a bounteous beast" instead of a "bounteous feast."
- In *substitution*, the speaker substitutes one language element for another. For example, you may have warned someone to do something "after it is too late," when you meant "before it is too late."
- In *reversal* (also called *transposition*), the speaker switches the positions of two language elements. An example is the reversal that reportedly led "flutterby" to become "butterfly." This reversal captivated language users so much that it is now the preferred form. Sometimes, reversals can be fortuitously opportune.
- In *spoonerisms*, the initial sounds of two words are reversed and make two entirely different words. The term is named after the Reverend William Spooner, who was famous for them. Some of his choicest slips include, "You have hissed all my mystery lectures," [missed all my history lectures] and "Easier for a camel to go through the knee of an idol" [the eye of a needle] (Clark & Clark, 1977).

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- In *malapropism*, one word is replaced by another that is similar in sound but different in meaning (e.g., furniture dealers selling "naughty pine" instead of "knotty pine").
- Additionally, slips may occur because of *insertions of sounds* (e.g., "mischiev*i*ous" instead of "mischievous" or "drown*d*ed" instead of "drowned") or other linguistic elements. The opposite kind of slip involves deletions (e.g., sound deletions such as "prossing" instead of "processing"). Such deletions often involve blends (e.g., "blounds" for "blended sounds").

Each kind of slip of the tongue may occur at different hierarchical levels of linguistic processing (Dell, 1986). That is, it may occur at the acoustical level of phonemes, as in "bounteous beast" instead of "bounteous feast." It may occur at the semantic level of morphemes, as in "after it's too late" instead of "before it's too late." Or it may occur at even higher levels, as in "bought the bucket" instead of "kicked the bucket" or "bought the farm." The patterns of errors (e.g., reversals, substitutions) at each hierarchical level tend to be parallel (Dell, 1986). For example, in phonemic errors, initial consonants tend to interact with initial consonants, as in "tasting wime" instead of "wasting time." Final consonants tend to interact with final consonants, as in "bing his tut" instead of "bit his tongue." Prefixes often interact with prefixes, as in "expiring expression," and so on.

Also, errors at each level of linguistic analysis suggest particular kinds of insights into how we produce speech. Consider, for example, phonemic errors. A stressed word, which is emphasized through speech rhythm and tone, is more likely to influence other words than is an unstressed word (Crystal, 1987). Furthermore, even when sounds are switched, the basic rhythmic and tonal patterns usually are preserved. An example is the emphasis on "hissed" and the first syllable of "mystery" in the first spoonerism quoted here.

Even at the level of words, the same parts of speech tend to be involved in the errors we produce (e.g., nouns interfere with other nouns, and verbs with verbs; Bock, 1990; Bock, Loebell, & Morey, 1992). In the second spoonerism quoted here, Spooner managed to preserve the syntactical categories, the nouns *knee* and *idol.* He also preserved the grammaticality of the sentence by changing the articles from "*a* needle" to "*an* idol." In the case of word substitutions, syntactic categories are preserved as well. In speech errors, semantic categories, too, may be preserved. An example would be naming a category when intending to name a member of the category, such as "fruit" for "apple." Another example would be naming the wrong member of the category, such as "peach" for "apple" (Garrett, 1992).

People who are fluent in sign language and mouth at the same time they sign have slips of the tongue (or hand) occurring independently of each other, indicating that oral words and sign words are not stored together in that person's lexicon (Vinson et al., 2010). A related phenomenon is having something on the tip of the tongue. The tip-of–the tongue phenomenon is discussed at the end of Chapter 4.

Another aspect of language that offers us a distinctive view is the study of metaphorical language.

Metaphorical Language

Until now, we have discussed primarily the literal uses of language. At least as interesting to poets and to many others is the nonliteral, figurative use of language. A notable example is the use of metaphors as a way of expressing thoughts. **Metaphors** juxtapose two nouns in a way that positively asserts their similarities, while not disconfirming their dissimilarities (e.g., the house was a pigsty, or abused children are walking time bombs). Related to metaphors are similes. **Similes** introduce the words *like* or *as* into a comparison between items (e.g., the child was as quiet as a mouse).

A prominent metaphor in cognitive psychology is that of humans as information processors. This metaphor highlights certain aspects of humans, such as our limited capacity for information processing. This limited capacity leads us to be selective in terms of what information to attend to in our environment (Newell & Bröder, 2008). Metaphors such as that of the human information processor guide scientific thinking and research as well as problem-solving strategies. When people were presented with a scenario of a city that had a high crime rate, they suggested different approaches depending on whether crime was described as a virus infecting the city or a beast attacking the city. In the virus condition, participants tended to suggest approaching the problem by investigating the roots of the high crime rates and then treating the problems (like poverty). In the beast conditions, suggested solutions were more direct (like catching and imprisoning the criminals; Thibodeau & Boroditsky, 2011, 2013).

Metaphors can enrich our speech in social contexts. For example, suppose we say to someone, “You are a prince.” Chances are that we do not mean that the person is literally a prince. Rather, we mean that the person has characteristics of a prince. How, in general, do we use language to negotiate social contexts? We explore the social contexts of language in the next section.

CONCEPT CHECK

1. What is linguistic relativity?
2. What impact can language have on the perception of color?
3. What is additive bilingualism?
4. Does age influence our ability to learn languages?
5. What are the single-system and dual-system hypotheses?
6. Name some kinds of slips of the tongue people make when they speak.

Language in a Social Context

The study of the social context of language is a relatively new area of linguistic research. One aspect of context is the investigation of **pragmatics**, the study of how people use language. It includes sociolinguistics and other aspects of the social context of language.

Under most circumstances, you change your use of language in response to contextual cues without giving these changes much thought. Similarly, you usually unselfconsciously change your language patterns to fit different contexts.

For example, in speaking with a conversational partner, you seek to establish common ground, or a shared basis for engaging in a conversation (Clark & Brennan, 1991). When we are with people who share background, knowledge, motives, or goals, establishing common ground is likely to be easy and scarcely noticeable. When little is shared, however, such common ground may be hard to find.

Another social context in which language is important is the Internet. People, and especially young people, often do not realize that their online interactions can have a real impact on their lives. One study, for example, showed that status updates on Facebook walls that contain misspelled words hurt ratings of that person’s employability as well as of the person’s intelligence and competence (Scott et al., 2014).

Gestures and vocal inflections, which are forms of nonverbal communication, can help establish common ground. One aspect of nonverbal communication is *personal space*—the distance between people in a conversation or other interaction that is considered comfortable for members of a given culture. *Proxemics* is the study of interpersonal distance or its opposite, proximity. It concerns itself with relative distancing and the positioning of you and your fellow conversants. In the United States, 2.45 feet to 2.72 feet is considered about right. In Mexico, the adequate distance ranges from 1.65 to 2.14 feet, whereas in Costa Rica it is between 1.22 and 1.32 feet (Baxter, 1970). Scandinavians expect more distance. Middle Easterners, southern Europeans, and South Americans expect less (Sommer, 1969; Watson, 1970).

INVESTIGATING
COGNITIVE PSYCHOLOGY

Language in Different Contexts

To get an idea of how you change your use of language in different contexts, suppose that you and your friend are going to meet right after work. Something comes up and you must call your friend to change the time or place for your meeting. When you call your friend at work, your friend's supervisor answers and offers to take a message. Exactly what will you say to your friend's supervisor to ensure that your friend will know about the change in time or location? Suppose, instead, that the supervisor's 4-year-old son answers. Exactly what will you say in this situation? Finally, suppose that your friend answers directly. How will you have modified your language for each context, even when your purpose (underlying message) in all three contexts was the same?

On familiar turf, we take our cultural views of personal space for granted. Only when we come into contact with people from other cultures do we notice these differences. For example, when Bob was visiting Venezuela, he noticed his cultural expectations coming into conflict with the expectations of those around him. He often found himself in a comical dance: He would back away from the person with whom he was speaking to increase his personal space; meanwhile, that person was trying to move closer. Within a given culture, greater proximity generally indicates one or more of three things. First, the people see themselves in a close relationship. Second, the people are participating in a social situation that permits violation of the bubble of personal space, such as close dancing. Third, the "violator" of the bubble is dominating the interaction.

Even within our own culture, there are differences in the amount of personal space that is expected. For instance, when two colleagues are interacting, the personal space is much smaller than when an employee and supervisor are interacting. When two women are talking, they stand closer together than when two men are talking (Dean, Willis, & Hewitt, 1975; Hall, 1966).

Does interpersonal distance also play a role in virtual-reality environments? When virtual worlds are created, a lot of factors matter in determining how believable the virtual worlds are. How people dress, how the streets look, and what sounds are in the background all facilitate or make it harder for people to immerse themselves in that environment. For example, when you visit a virtual place located in Latin America, you expect to see people who look Latin American. To create lifelike simulations, it also matters how people behave during interpersonal interactions. How close do they stand together, how often do they look at each other, and how long do they keep that gaze?

Computational models are being developed to simulate the behavior of people from different cultures (Jan et al., 2007).

Violations of personal space, even in virtual environments, cause discomfort (Wilcox et al., 2006). When given the option, people whose personal space is violated in a virtual environment will move away (Bailenson et al., 2003). Physical space is also maintained in video conferencing (Grayson & Coventry, 1998).

These findings on proxemics indicate the importance of interpersonal space in all interactions. They also indicate that proxemics is important, even when one or more of the people are not physically present.

Characteristics of Successful Conversations

In speaking to each other, we implicitly set up a cooperative enterprise. If we do not cooperate with each other when we speak, we often end up talking past rather than to each other. In other words, we fail to communicate what we intended. Conversations thrive on the basis of a **cooperative principle**, by which we seek to communicate in ways that make it easy for our listener to understand what we mean (Grice, 1967; Mooney, 2004). According to Grice, successful conversations follow four maxims: the maxim of quantity, the maxim of quality, the maxim of relation, and the maxim of manner. Examples of these maxims are provided in Table 10.1 ■.

We might add an additional maxim: Only one person speaks at a time (Sacks, Schegloff, & Jefferson, 1974). The situational context and the relative social positions of the speakers affect turn-taking (Keller, 1976). Sociolinguists have noted many ways in which speakers signal to one another when and how to take turns. Sometimes people use the conversational maxims to make a point. For example, suppose one says, “My

Table 10.1 Conversational Maxims

To maximize the communication that occurs during conversation, speakers generally follow four maxims.

Maxim	Definition	Example
Quantity	Make your contribution to a conversation as informative as required, but no more than is needed.	If someone asks you the temperature outside and you reply, “It’s 31.297868086298 degrees out there,” you are violating the maxim of quantity because you are giving more information than required.
Quality	Make your contribution to a conversation truthful. Irony, sarcasm, and jokes are acceptable because the listener is expected to infer the speaker’s true state of mind from what is said.	There are awkward circumstances in which each of us is unsure of just how much honesty is being requested. Most communication, however, depends on an assumption that both parties to the communication are being truthful.
Relation	Make your contributions to a conversation relevant to the aim of the conversation.	During a meeting someone may violate this maxim by going into long digressions unrelated to the purpose of the meeting: “That reminds me of a story a friend once told me about a meeting he once attended, where . . . ”
Manner	Avoid obscure expressions, vague utterances, and purposeful obfuscation of your point.	Nobel Prize–winning physicist Richard Feynman (1997) once read a sentence that went something like this: “The individual member of the social community often receives information via visual, symbolic channels” (p. 281). Realizing the sentence meant, “People read,” Feynman concluded that the scholar was violating the maxim of manner.

parents are wardens." One is not providing full information (what, exactly, does it mean for one's parents to be wardens?). But the ambiguity is intentional. Or sometimes when a conversation on a topic becomes heated, one purposely may switch topics and bring up an irrelevant issue. One's purpose in doing so is to get the conversation to another, safer topic. When we use the maxims, we are sending an explicit message by doing so: The maxims retain their importance because their absence is so notable.

People with autism spectrum disorder have difficulty with both language and emotion. It is therefore not surprising that they have particular difficulty in detecting violations of the Gricean maxims (Eales, 1993; Surian, 1996). Further discussion of language impairments in people with autism spectrum disorder are discussed later in the chapter.

Gender and Language

Do men and women speak a different language in our culture? Gender differences have been found in the content of what we say. Young girls are more likely to ask for help than are young boys (Thompson, 1999). Girls also text differently than boys; boys often view girls' texts as long and containing unnecessary elements, whereas texts written by boys may seem brisk and short to girls (Ling et al., 2014). Older adolescent and young adult males prefer to talk about political views, sources of personal pride, and what they like about the other person. In contrast, females in this age group prefer to talk about feelings toward parents, close friends, classes, and their fears (Rubin et al., 1980). Also, in general, women seem to disclose more about themselves than do men (Morton, 1978).

Conversations between men and women are sometimes regarded as cross-cultural communication (Tannen, 1986, 1990, 1994). Young girls and boys learn conversational communication in essentially separate cultural environments through their same-sex friendships. As men and women, we then carry over these conversational styles we have learned in childhood, into our adult conversations.

Male–female differences in conversational style largely center on differing understandings of the goals of conversation, according to Tannen. These cultural differences result in contrasting styles of communication. These in turn can lead to misunderstandings and even break-ups as each partner somewhat unsuccessfully tries to understand the other. According to Tannen (1990, 1994), men see the world as a hierarchical social order in which the purpose of communication is to negotiate for the upper hand, to preserve independence, and to avoid failure. Each man strives to one-up the other and to "win" the contest. Women, in contrast, seek to establish a connection between the two participants, to give support and confirmation to others, and to reach consensus through communication.

To reach their conversational goals, women use conversational strategies that minimize differences, establish equity, and avoid any appearances of superiority on the part of one or another conversant. Women also affirm the importance of and the commitment to the relationship. They handle differences of opinion by negotiating to reach a consensus that promotes the connection and ensures that both parties at least feel that their wishes have been considered. They do so even if they are not entirely satisfied with the consensual decision.

Men enjoy connections and rapport. But because men have been raised in a gender culture in which status plays an important role, other goals take precedence in conversations. Men seek to assert their independence from their conversational partners, suggests Tannen. In this way, they clearly indicate their lack of acquiescence to the demands of others, which would indicate lack of power. Men also prefer to inform (thereby indicating the higher status conferred by authority) rather than to consult (indicating subordinate status) with their conversational partners. The male partner in a close relationship thus may end up informing his partner of their plans. In contrast, the female partner expects to be consulted on their plans. When men and women engage in cross-gender communications, their crossed purposes often result in miscommunication because each partner misinterprets the other's intentions.

Men and women need to become more aware of their cross-cultural styles and traditions, suggests Tannen. In this way, they may at least be less likely to misinterpret one another's conversational interactions. They are also both more likely to achieve their individual aims, the aims of the relationship, and the aims of the other people and institutions affected by their relationship. Such awareness is important not only in conversations between men and women but also in conversations among family members in general (Tannen, 2001).

Gender differences in written language also have been observed (Argamon et al., 2003). For example, a study that analyzed more than 14,000 text files from 70 separate studies found that women used more words that were related to psychological and social processes, whereas men related more to object properties and impersonal topics (Newman et al., 2008). On web forums, too, women are more likely to express their emotions, both positive and negative (Zhang, Dang, & Chen, 2013). These findings, however, are not conclusive. A study examining blogs noted that the type of blog, more than the gender of the author, dictated the writing style (Herring & Paolillo, 2006).

Thus far we have discussed the social and cognitive contexts for language. Language use interacts with, but does not completely determine, the nature of thought. Social interactions influence the ways in which language is used and comprehended in discourse and reading. Next, we highlight some of the insights we have gained by studying the physiological context for language. Specifically, how do our brains process language? And do nonhuman animals have language?

CONCEPT CHECK

1. What are some forms of nonverbal communication?
2. What are some maxims of successful conversations?
3. How does gender have an impact on language?

Do Animals Have Language?

Language is often seen as one thing that differentiates humans from animals. Some cognitive psychologists even specialize in the study of nonhuman animals. Why would they study such animals, when humans are so readily available? Researchers study nonhuman animals for several reasons.

First, nonhuman animals often are presumed to have somewhat simpler cognitive systems. It is therefore easier to model their behavior.

Second, nonhuman animals can be subject to procedures that would not be possible for human ones. For example, a rat may be sacrificed at the end of a learning experiment to study changes that have occurred in the brain as a result of learning.

Third, nonhuman animals that are not in the wild can serve as full-time subjects, or at least, regularly available subjects. They are typically available whenever the experimenter needs them.

Fourth, an understanding of the comparative and evolutionary as well as developmental bases of human behavior requires studies of various nonhuman animals

(Rumbaugh & Beran, 2003). If cognitive psychologists want to understand the origins of human cognition in the distant past, they need to study other kinds of animals besides humans.

The philosopher René Descartes (1596–1650) suggested that language is what qualitatively distinguishes human beings from other species. Was he right? Before we get into the particulars of language in nonhuman species, we should emphasize the distinction between communication and language. Few would doubt that nonhuman animals communicate in one way or another. What is at issue is whether they do so through what reasonably can be called a *language*. Whereas *language* is an organized means of combining words to communicate, *communication* more broadly encompasses not only the exchange of thoughts and feelings through language but also nonverbal expression. Examples include gestures, glances, distancing, and other contextual cues.

Primates—especially chimpanzees—offer our most promising insights into nonhuman language. Jane Goodall, the well-known investigator of chimpanzees in the wild, has studied diverse aspects of chimp behavior. Goodall considers many chimp vocalizations as clearly communicative, but not necessarily indicative of language. For example, chimps have a specific cry indicating that they are about to be attacked. They have another for calling their fellow chimps together. Nonetheless, their repertoire of communicative vocalizations seems to be small, nonproductive (new utterances are not produced), limited in structure, lacking in structural complexity, and relatively nonarbitrary. It also is not spontaneously acquired. The chimps' communications thus do not satisfy our criteria for a language.

But can chimps be taught to use language by humans? Several researchers have tried to teach chimps language skills. The vocal tract of chimpanzees is different from the one of humans, so they are unable to reproduce the majority of human sounds. Instead, researchers have reverted to teaching them sign language.

The best evidence of language use among chimpanzees was found by Savage-Rumbaugh et al. (1986, 1993). Their pygmy chimpanzees spontaneously combined the visual symbols (such as red triangles and blue squares) of an artificial language the

Jens Shlueter/AFP/Getty Images

Jane Goodall communicates with a chimpanzee.

researchers taught them. They even appear to have understood some of the language spoken to them. One pygmy chimp in particular (Greenfield & Savage-Rumbaugh, 1990) seemed to possess remarkable skill, even possibly demonstrating a primitive grasp of language structure. The difference in results across groups of investigators may be explained by the particular kind of chimp tested or to the procedures used. The chimp's language may not meet all the constraints posed by the properties of language described at the beginning of this chapter. For example, the language used by the chimps is not spontaneously acquired. Rather, they learn it only through deliberate and systematic programs of instruction.

Another famous exploration of language in a nonhuman can be seen in the gorilla Koko. Koko can use approximately 1,000 signs and can communicate quite effectively with humans, expressing both desires and thoughts. Evidence also suggests that Koko is able to understand and use humor (Gamble, 2001). Koko also seems to be able to use language in a novel way, both combining signs in new ways and by forming entirely new signs. One of the most famous examples of this behavior was exhibited when Koko developed a new sign for "ring" by combining "finger" and "bracelet" (Hill, 1978).

A neuroanatomical study of chimpanzees found that when chimps use tools, the brain regions that were especially active corresponded to Broca's and Wernicke's areas in humans. Both of those areas are associated with language comprehension and production, and it has been hypothesized that the use of tools in early humans actually facilitated the development of language (Hopkins, Russell, & Cantalupo, 2007).

A less positive view of the linguistic capabilities of chimpanzees was taken by Herbert Terrace (1987), who raised a chimp named Nim Chimpsky, a takeoff on Noam Chomsky, the eminent linguist. Over the course of several years, Nim made more than 19,000 multiple-sign utterances in a slightly modified version of American Sign Language. Most of his utterances consisted of two-word combinations. Terrace's careful analysis of these utterances, however, revealed that most of them were repetitions of what Nim had seen. Terrace concluded that, despite what appeared to be impressive accomplishments, Nim did not show even the rudiments of syntactical expression. The chimp could produce single- or even multiple-word utterances, but not in a syntactically organized way. For example, Nim would alternate signing, "Give Nim banana," "Banana give Nim," and "Banana Nim give," showing no preference for the grammatically correct form. Moreover, Terrace also studied films showing other chimpanzees supposedly producing language. He came to the same conclusion for them that he had reached for Nim. His position, then, is that although chimpanzees can understand and produce utterances, they do not have linguistic competence in the same sense that even very young humans do. Their communications lack structure, and particularly multiplicity of structure. At this point, we just cannot be sure whether chimps truly show the full range of language abilities.

Chimpanzees are not the only ones that can learn language to a certain extent—other species can as well. Take the example of Alex, an African Grey Parrot who died in 2007. Alex could produce more than 200 words and express a variety of complex concepts, including *present* and *absent* and a zero-like concept. Recent evidence also suggests that Alex was capable of novel combinations of words to form new ways of expressing concepts (Pepperberg, 1999, 2007; Pepperberg & Gordon, 2005).

Whether nonhuman species can use language, it seems almost certain that the language facility of humans far exceeds that of other species psychologists have studied. Noam Chomsky (1991) eloquently stated the key question regarding nonhuman language: "If an animal had a capacity as biologically advantageous as language but somehow hadn't used it until now, it would be an evolutionary miracle, like finding an island of humans who could be taught to fly."

CONCEPT CHECK

1. Why do psychologists conduct research with animals?
2. Do animals have the same potential for language as humans? Explain.

Neuropsychology of Language

In this part of the chapter, we first will explore which parts of the brain are involved in language production and comprehension. Afterward, we will turn our attention to specific instances of language impairment. Recall from Chapter 2 that some of our earliest insights into brain localization are related to an association between specific language deficits and specific organic damages to the brain, as first discovered by Marc Dax, Paul Broca, and Carl Wernicke (see also Brown & Hagoort, 1999; Garrett, 2003). Broca's aphasia and Wernicke's aphasia are particularly well-documented instances in which brain lesions affect linguistic functions.

Brain Structures Involved in Language

Through studies of patients with brain lesions, researchers have learned a great deal about the relations between particular areas of the brain (the areas of lesions observed in patients) and particular linguistic functions (the observed deficits in the brain-injured patients). Recent imaging studies of the post-traumatic recovery of linguistic functioning find, however, that neurological language functioning can redistribute to other areas of the brain. Thus, damage to the major left hemisphere areas responsible for language functioning sometimes can lead to enhanced involvement of other areas as language functioning recovers. It is as if previously dormant or overshadowed areas take over the vacant duties (Cappa et al., 1997; Rosenberg et al., 2008). This process is also known as *neuroplasticity*.

The Brain and Word Recognition

One avenue of research involves the study of the metabolic activity of the brain and the flow of blood in the brain during the performance of various verbal tasks. Functional magnetic resonance imaging (fMRI) studies have found that the middle part of the superior temporal sulcus (STS) responds more strongly to speech sounds than to nonspeech sounds. The response takes place in both sides of the STS, although it is usually stronger in the left hemisphere. Interestingly, it does not matter whether words or pseudo-words are presented. This means it is unlikely that processing of semantic information takes place here (Binder, 2009; Binder et al., 1996, 2000; Desai et al., 2005).

The Brain and Semantic Processing

Where does semantic processing take place then? Research shows a relatively consistent picture. Five brain regions are involved in the storage and retrieval of meaning (Binder, 2009; see Figure 10.4 ■):

- the *ventral temporal lobes*, including middle and inferior temporal, anterior fusiform, and anterior parahippocampal gyri
- the *angular gyrus*

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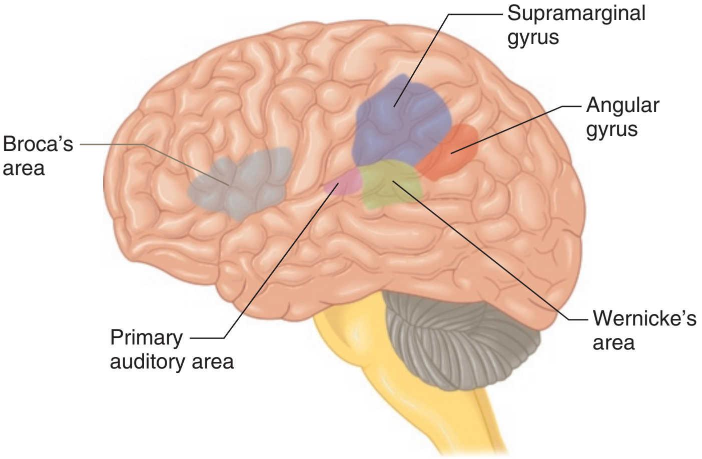

Figure 10.4 These brain areas are involved in semantic processing.

- the anterior aspect (pars orbitalis) of the *inferior frontal gyrus*
- the *dorsal prefrontal cortex*
- the *posterior cingulate gyrus*

The activation of these areas takes place mostly in the left hemisphere, although there is some activation in the right hemisphere. It is suspected that the right hemisphere does not play a significant role in word recognition, but study results are not clear on this (Binder, 2009; Gerlach et al., 2014; Vandenbulcke, 2006). Surgeons sometimes conduct brain surgery while patients are awake to map the language pathways and try to preserve the language capabilities of their patients after surgery (Duffau et al., 2008).

The Brain and Gender Differences in Language Processing

Dominance of the left hemisphere is observed for most language users in studies employing brain-imaging techniques like fMRI (Anderson et al., 2006; Gaillard et al., 2004). Men and women appear to process language differently, at least at the phonological level (Shaywitz, 2005). An fMRI study of men and women asked participants to perform one of four tasks:

1. indicate whether a pair of letters was identical
2. indicate whether two words have the same meaning
3. indicate whether a pair of words rhymes
4. compare the lengths of two lines (a control task)

The researchers found that when both male and female participants were performing the letter-recognition and word-meaning tasks, they showed activation in the left temporal lobe of the brain. When they were performing the rhyming task, however, different areas were activated for men versus women. Only the inferior (lower) frontal region of the left hemisphere was activated for men. The inferior frontal region of both the left and right hemispheres was activated in women. These results suggested that men localized their phonological processing more than did women.

There are intriguing sex differences in how linguistic function is localized in the brain (Kimura, 1987). Men seem to show more left-hemisphere dominance for linguistic function than the women show. Women show more bilateral, symmetrical patterns of linguistic function. Furthermore, the brain locations associated with aphasia

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(loss of speech as a result of brain damage) seemed to differ for men and women. Most aphasic women showed lesions in the anterior region, although some aphasic women showed lesions in the temporal region. In contrast, aphasic men showed a more varied pattern of lesions. Aphasic men were more likely to show lesions in posterior regions rather than in anterior regions. One interpretation of Kimura's findings is that the role of the posterior region in linguistic function may be different for women than it is for men.

Another interpretation relates to the fact that women show less lateralization of linguistic function. Women may be better able to compensate for any possible loss of function because of lesions in the left posterior hemisphere through functional offsets in the right posterior hemisphere. The possibility that there also may be subcortical sex differences in linguistic function further complicates the ease of interpreting Kimura's findings. (Recall also the earlier discussion of communication differences between men and women.) A recent meta-analysis, however, could not verify any sex differences in asymmetries of the Planum Temporale (which is at the center of Wernicke's area) or in functional imaging findings during language tasks (Sommer et al., 2008).

Despite the many findings that have resulted from studies of brain-injured patients, there are two key difficulties in drawing conclusions based only on studies of patients with lesions:

1. Naturally occurring lesions are often not easily localized to a discrete region of the brain, with no effects on other regions. For example, when hemorrhaging or insufficient blood flow (such as impairment due to clotting) causes lesions, the lesions also may affect other areas of the brain. Thus, many patients who show cortical damage also have suffered some damage in subcortical structures. This may confound the findings of cortical damage.
2. Researchers are able to study the linguistic function of patients only after the lesions have caused damage. Typically they are unable to document the linguistic function of patients before the damage.

Because it would be unethical to create lesions merely to observe their effects on patients, researchers are able to study the effects of lesions only in those areas where lesions happen to have occurred naturally. Other areas therefore are not studied.

Researchers also investigate brain localization of linguistic functions via electrical stimulation of the brain. Gender differences have been investigated this way as well, which has revealed a somewhat paradoxical interaction of language and the brain (Ojemann, 1982). Although females generally have superior verbal skills compared with males, males have a proportionately larger (more diffusely dispersed) language area in their brains. Counterintuitively, therefore, the size of the language area in the brain may be related inversely to the ability to use language.

The Brain and Sign Language

Kimura (1981) also has studied hemispheric processing of language in people who use sign language rather than speech to communicate. She found that the locations of lesions that would be expected to disrupt speech also disrupt signing. Furthermore, the hemispheric pattern of lesions associated with signing deficits is the same pattern shown with speech deficits. That is, all right-handers with signing deficits show left-hemisphere lesions, as do most left-handers. But some left-handers with signing deficits show right-hemisphere lesions (see also Newman et al., 2010; Pickell et al., 2005). This finding supports the view that the brain processes both signing and speech similarly in terms of their linguistic function. It refutes the view that signing involves spatial processing or some other nonlinguistic form of cognitive processing.

Aphasia

Aphasia is an impairment of language functioning caused by damage to the brain (Caramazza & Shapiro, 2001; Garrett, 2003; Hillis & Caramazza, 2003; see Figure 10.5 ■). There are several types of aphasias.

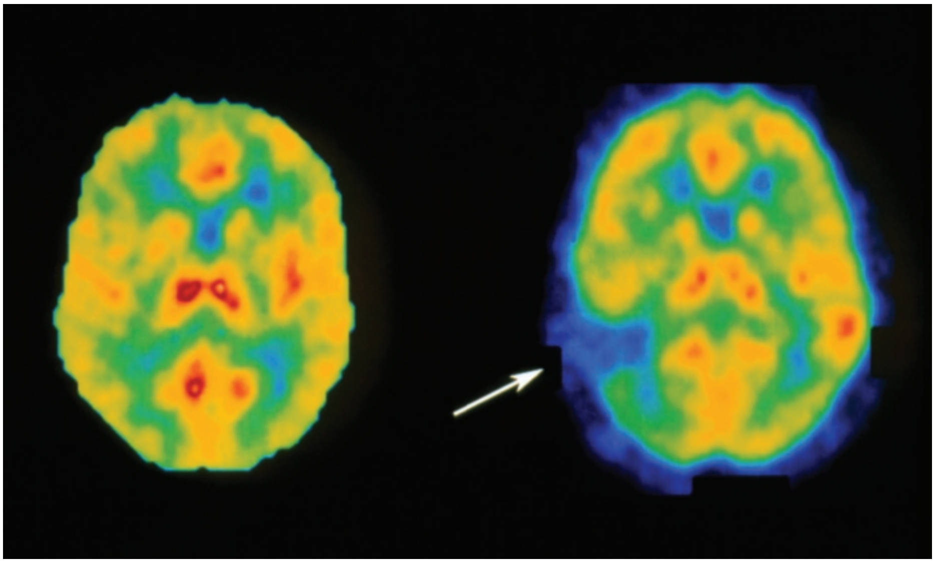
Wernicke's Aphasia

Wernicke's aphasia is caused by damage to Wernicke's area of the brain (see Chapter 2). It is characterized by notable impairment in the understanding of spoken words and sentences. It also typically involves the production of sentences that have the basic structure of the language spoken but that make no sense. Two examples are "Yeah, that was the pumpkin furthest from my thoughts" and "the scroolish prastimer ate my spanstakes" (Hillis & Caramazza, 2003, p. 176). In the first case, the words make sense, but not in the context they are presented. In the second case, the words themselves are neologisms, or newly created words. Treatment for patients with this type of aphasia frequently involves supporting and encouraging nonlanguage communication (Altschuler et al., 2006).

Broca's Aphasia

Broca's aphasia is caused by damage to Broca's area of the brain (see Chapter 2). It is characterized by the production of agrammatical speech at the same time that verbal comprehension ability is largely preserved. It thus differs from Wernicke's aphasia in two key respects. First, the speech is agrammatical rather than grammatical (as in Wernicke's). Second, the verbal comprehension is largely preserved. An example of a production by a patient with Broca's aphasia is "Stroke . . . Sunday . . . arm, talking—bad" (Hillis & Caramazza, 2003, p. 176). The gist of the intended sentence is maintained, but the expression of it is badly distorted. Broca's area is important for speech production, regardless of the format of the speech. In particular, Broca's area is activated during imagined or actual sign production (Campbell, MacSweeney, & Waters, 2007; Horwitz et al., 2003).

■ Figure 10.5 Brain scans comparing the brain of a normal patient (left) with the brain of an aphasic patient.



Wellcome Depart. of Cognitive Neurology/Science Photo Library

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Global Aphasia

Global aphasia is the combination of highly impaired comprehension and production of speech. It is caused by lesions to both Broca's and Wernicke's areas. Aphasia following a stroke frequently involves damage to both Broca's and Wernicke's areas. In one study, researchers found 32% of aphasias immediately following a stroke involved both Broca's and Wernicke's areas (Pedersen, Vinter, & Olsen, 2004).

Anomic Aphasia

Anomic aphasia involves difficulties in naming objects or in retrieving words. The patient may look at an object and simply be unable to retrieve the word that corresponds to the object. Sometimes, specific categories of things cannot be recalled, such as names of living things (Jonkers & Bastiaanse, 2007; Mårtensson et al., 2014; Warrington & Shallice, 1984).

Autism Spectrum Disorder

Autism spectrum disorder is a developmental disorder characterized by abnormalities in social behavior, language, and cognition (Heinrichs, Dawansa, & Domes, 2009; Pierce & Courchesne, 2003). It is biological in its origins, and researchers have already identified some of the genes associated with it (Wall et al., 2009). Children with autism show abnormalities in many areas of the brain, including the frontal and parietal lobes, as well as the cerebellum, brainstem, corpus callosum, basal ganglia, amygdala, and hippocampus. About half of children with autism fail to develop functional speech. What speech they do develop tends to be characterized by *echolalia,* meaning they repeat, over and over again, speech they have heard. Sometimes the repetition occurs several hours after the original use of the words by someone else (Grossi et al., 2013; Pierce & Courchesne, 2003). People with autism also may have problems with the semantic encoding of language (Binder, 2009).

CONCEPT CHECK

1. Which parts of the brain are involved in semantic processing?
2. What does "plasticity" refer to with respect to the brain?
3. What are some difficulties when drawing conclusions from lesion studies?
4. What is the difference between Wernicke's aphasia and Broca's aphasia?

Key Themes

This chapter deals with several of the themes highlighted in Chapter 1.

Validity of causal inference versus ecological validity. Some researchers study language comprehension and production in controlled laboratory settings. For example, studies of phonology are likely to occur in a laboratory where it is possible to gain precise experimental control of stimuli. But work on language and thought often is done in remote parts of the world where tight experimental controls are only a dream. Studies of language usage in remote African villages, for example, typically cannot be done with tight controls, although some control is possible. As always, a combination of methodologies best enables cognitive psychologists to understand psychological phenomena to their fullest.

Biological versus behavioral methods. Lesion studies are a particularly good example of a combination of the two methodologies. On the one hand, they require a deep understanding of the nature of the brain and the parts of the brain affected by particular lesions. On the other hand, researchers examine behavior to understand how the particular lesions, and by inference, parts of the brain, are related to behavioral functioning.

Structure versus process. To understand any linguistic phenomena, one must analyze thoroughly the structure of the language under investigation. One can then investigate the processes that are used to comprehend and produce this language. Without an understanding of both structure and process, it would be impossible to fully understand language and thought.

Suppose you are on a camping trip and are sitting around the campfire at night, admiring the numerous stars in the sky. Imagine asking someone the following metaphorical question, "Would you like to see the sun paint a picture across the morning sky?" What does this question mean? Some people might say that it means that you are asking if they would like to wake up early to see how beautiful the sunrise will be the next morning. Others might say it means that it is getting late and that you should go to sleep to wake up early to see the beautiful sunrise. Now, suppose you ask this same question not on a camping trip but in a sleazy bar. What do you think the utterance will mean in that context?

SUMMARY

1. **How does language affect the way we think?** According to the linguistic-relativity view, cognitive differences that result from using different languages cause people speaking the various languages to perceive the world differently. However, the linguistic-universals view stresses cognitive commonalities across different language users. No single interpretation explains all the available evidence regarding the interaction of language and thought.

   Research on bilinguals seems to show that environmental considerations also affect the interaction of language and thought. For example, additive bilinguals have established a well-developed primary language. The second language adds to their linguistic and perhaps even their cognitive skills. In contrast, subtractive bilinguals have not yet firmly established their primary language when portions of a second language partially displace the primary language. This displacement may lead to difficulties in verbal skills. Theorists differ in their views as to whether bilinguals store two or more languages separately (dual-system hypothesis) or together (single-system hypothesis). Some aspects of multiple languages possibly could be stored separately and others unitarily. Creoles and pidgins arise when two or more distinct linguistic groups come into contact. A dialect appears when a regional variety of a language becomes distinguished by features as distinctive vocabulary, grammar, and pronunciation.

   Slips of the tongue may involve inadvertent verbal errors in phonemes, morphemes, or larger units of language. Slips of the tongue include anticipations, perseverations, reversals (including spoonerisms), substitutions, insertions, and deletions.

2. **How does our social context influence our use of language?** Psychologists, sociolinguists, and others who study pragmatics are interested in how language

is used within a social context. Their research looks into various aspects of nonverbal as well as verbal communication. Conversational maxims provide a means for establishing language as a cooperative enterprise. They include several maxims, including the maxims of quantity, quality, relation, and manner. Sociolinguists have observed that people engage in various strategies to signal turn-taking in conversations.

Sociolinguistic research suggests that male–female differences in conversational style center largely on men's and women's differing understandings of the goals of conversation. It has been suggested that men tend to see the world as a hierarchical social order in which their communication aims involve the need to maintain a high rank in the social order. In contrast, women tend to see communication as a means for establishing and maintaining their connection to their communication partners. To do so, they seek ways to demonstrate equity and support and to reach consensual agreement.

In discourse and reading comprehension, we use the surrounding context to infer the reference of pronouns and ambiguous phrases. The discourse context also can influence the semantic interpretation of unknown words in passages and aid in acquiring new vocabulary. Propositional representations of information in passages can be organized into mental models for text comprehension. Finally, a person's point of view likewise influences what will be remembered.

3. **How can we find out about language by studying the human brain, and what do such studies reveal?** Neuropsychologists, cognitive psychologists, and other researchers have managed to link quite a few language functions with specific areas or structures in the brain. They observe what happens when a particular area of the brain is injured, is electrically stimulated, or is studied in terms of its metabolic activity. For most people, the left hemisphere of the brain is vital to speech. It affects many syntactical aspects and some semantic aspects of linguistic processing. For most people, the right hemisphere handles a more limited number of linguistic functions. They include auditory comprehension of semantic information, as well as comprehension and expression of some nonliteral aspects of language use. These aspects involve vocal inflection, gesture, metaphors, sarcasm, irony, and jokes.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Why are researchers interested in the number of color words used by different cultures?
2. How should cognitive psychologists interpret evidence of linguistic universals when considering the linguistic-relativity hypothesis?
3. Compare and contrast the kinds of understandings that can be gained by studying speech errors made by healthy people with those that can be gained by studying the language produced by people who have particular brain lesions.
4. Write an example of a pidgin conversation between two people and a creole conversation, focusing on the differences between pidgins and creoles.
5. Draft an example of a brief dialogue between a male and a female in which each may misunderstand the other, based on their differing beliefs regarding the goals of communication.

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6. Suppose that you are an instructor of English as a second language. What kinds of things will you want to know about your students to determine how much to emphasize phonology, vocabulary, syntax, or pragmatics in your instruction?
7. Give an example of a humorous violation of one of Grice's four maxims of successful conversation.

KEY TERMS

aphasia, p. 394
bilinguals, p. 376
cooperative principle, p. 386
dialect, p. 380
dual-system hypothesis, p. 378
linguistic relativity, p. 370
linguistic universals, p. 371
metaphors, p. 383
monolinguals, p. 376
pragmatics, p. 384
similes, p. 384
single-system hypothesis, p. 378
slips of the tongue, p. 382

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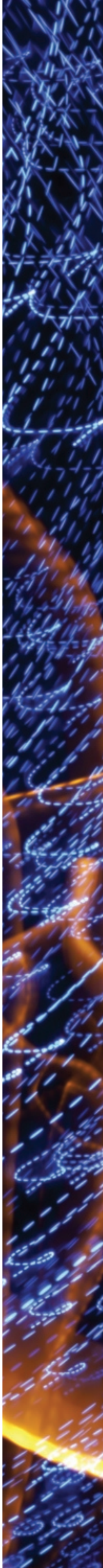
11

Problem Solving and Creativity



CHAPTER OUTLINE

- **The Problem-Solving Cycle**
- **Types of Problems**
  - Well-Structured Problems
    - Isomorphic Problems
    - Problem Representation Does Matter
  - Ill-Structured Problems and the Role of Insight
    - Early Gestaltist Views
    - The Neo-Gestaltist View
    - Insights into Insight
    - Neuroscience and Insight
- **Obstacles and Aids to Problem Solving**
  - Mental Sets, Entrenchment, and Fixation
  - Negative and Positive Transfer
    - Transfer of Analogies
    - Intentional Transfer: Searching for Analogies
  - Incubation
  - Embodied Cognition and Problem Solving
  - Neuroscience and Planning during Problem Solving
- **Expertise: Knowledge and Problem Solving**
  - Organization of Knowledge
    - Elaboration of Knowledge
    - Reflections on Problem Solving
    - Automatic Expert Processes
  - Long-Term Working Memory and Expertise
  - Innate Talent and Acquired Skill
- **Creativity**
  - Characteristics of Creative People
  - Neuroscience and Creativity
- **Key Themes**
- **Summary**
- **Thinking about Thinking: Analytical, Creative, and Practical Questions**
- **Key Terms**
- **Media Resources**

■ **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the lab title and number for easy access. Go to **CogLab.Cengage.com.**

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Here are some of the questions we will explore in this chapter:

1. What are some key steps involved in solving problems?
2. What are the differences between problems that have a clear path to a solution versus problems that do not?
3. What are some of the obstacles and aids to problem solving?
4. How does expertise affect problem solving?
5. What is creativity, and how can it be fostered?

BELIEVE IT OR NOT | Can Novices Have an Advantage over Experts?

An expert has invested countless hours into his field of study—be it playing a musical instrument, doing academic research, or playing chess. Does having this expertise always pay off? Research suggests that sometimes having less knowledge—being a novice—actually gives you an edge. In one experiment, researchers had expert and novice chess players briefly view a display of a chessboard with the chess pieces on it, and the players then had to recall the positions of the chess pieces on the board. As you might expect, the experts performed quite a bit better than the novices. However, the setup of the chess pieces on the board was then changed in a way that it did not make sense in terms of the actual game of chess. Suddenly, experts lost their advantage and performed no better, or even worse, than did the novices (Chase & Simon, 1973; see also Brockmole et al., 2008). Likewise, Frensch and Sternberg (1989) found that when a strategic change was made in the rules for the card game bridge, experts were hurt more than novices, presumably because the experts had become entrenched and somewhat stuck with the conventional set of rules. We will explore possible reasons for this effect later in this chapter in the section on expertise.

How do you solve problems in your relationships with other people? How do you solve the “two-string” problem illustrated in Figure 11.1 ■? How does anyone solve any problem, for that matter? This chapter considers the process of solving problems, as well as some of the hindrances and aids to **problem solving**, an effort to overcome obstacles obstructing the path to a solution (Reed, 2000). At the conclusion of this chapter, we discuss creativity and its role in problem solving. Throughout the chapter, we discuss how people make the “mental leaps” that lead them from having a set of givens to having a solution to a problem (Holyoak & Thagard, 1995).

This chapter focuses on individual problem solving. It is worth remembering, however, that working in groups often facilitates problem solving. The solutions reached by groups often are better than those reached by individuals (Williams & Sternberg, 1988). This benefit is seen most notably when the group members represent a variety of ability levels (Hong & Page, 2004). We engage in problem solving when we need to overcome obstacles to answer a question or to achieve a goal. If we quickly can retrieve an answer from memory, we do not have a problem. If we cannot retrieve an immediate answer, then we have a problem to be solved.

How people solve problems depends partly on how they understand the problem (Whitten & Graesser, 2003). Consider an example of how understanding the nature of the problem matters.

People are told the following about a drug that has been newly developed and that is supposed to cure a mysterious illness (Stanovich, 2003; Stanovich & West, 1999):

	Cured	Not Cured
Received Drug	150	150
Did Not Receive Drug	300	75

The question is whether the drug is helpful in curing the disease. When given the above information about the drug, are people able to interpret it correctly? Look at the data again. Does the drug cure the mysterious disease, or does it not work? Many people believe that the drug in this instance is helpful. In fact, the drug described is not helpful at all. On the contrary, it is harmful. Only 50% of the people who received the drug were cured (i.e., 150 of 300). In contrast, 80% of the people who did not receive the drug were cured (300 of 375). ■ See also Lab 50, Monty Hall, in CogLab.

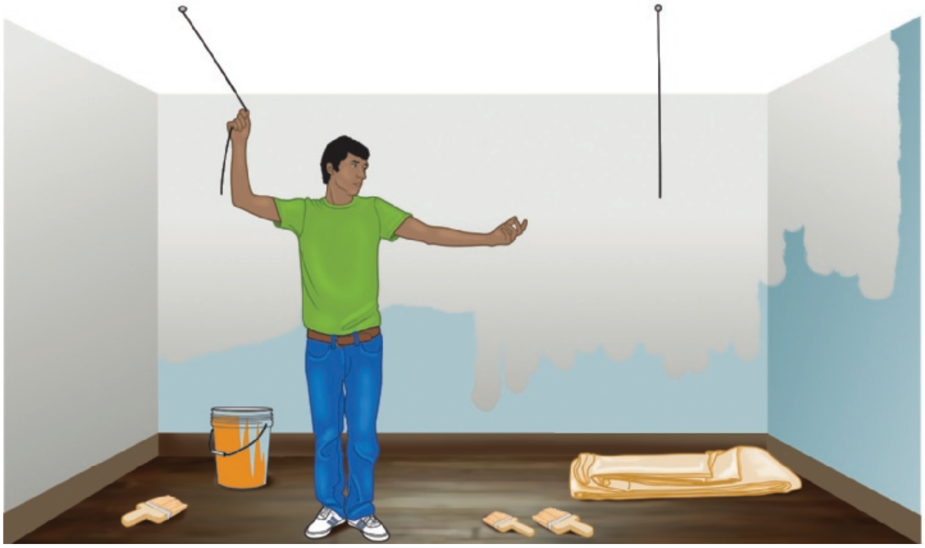

Figure 11.1 **The String Problem.** Imagine standing in the middle of this room where two strings are hanging down from the ceiling. Your goal is to tie together the two strings, but neither string is long enough to reach out and grab the other string while holding either of the two strings. You have a few clean paintbrushes, a can of paint, and a heavy canvas tarpaulin. How will you tie together the two strings? If you have trouble finding a solution, look at Figure 11.6.

Source: Based on Richard E. Mayer, "The Search for Insight: Grappling with Gestalt Psychology's Unanswered Questions," in *The Nature of Insight*, edited by R. J. Sternberg and J. E. Davidson. © 1995 MIT Press.

The Problem-Solving Cycle

When we are trying to solve problems, we are confronted with what is often called the *initial state*, that is, the situation at the outset in which the problem is not yet solved. We strive to reach the *goal state*, which is the condition under which the problem has been

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solved. However, our way to the goal state (i.e., the solution of our problem) is blocked by an *obstacle*—one or many factors that prevent us from solving our problem. When we attempt to solve a problem, we engage in a problem-solving cycle.

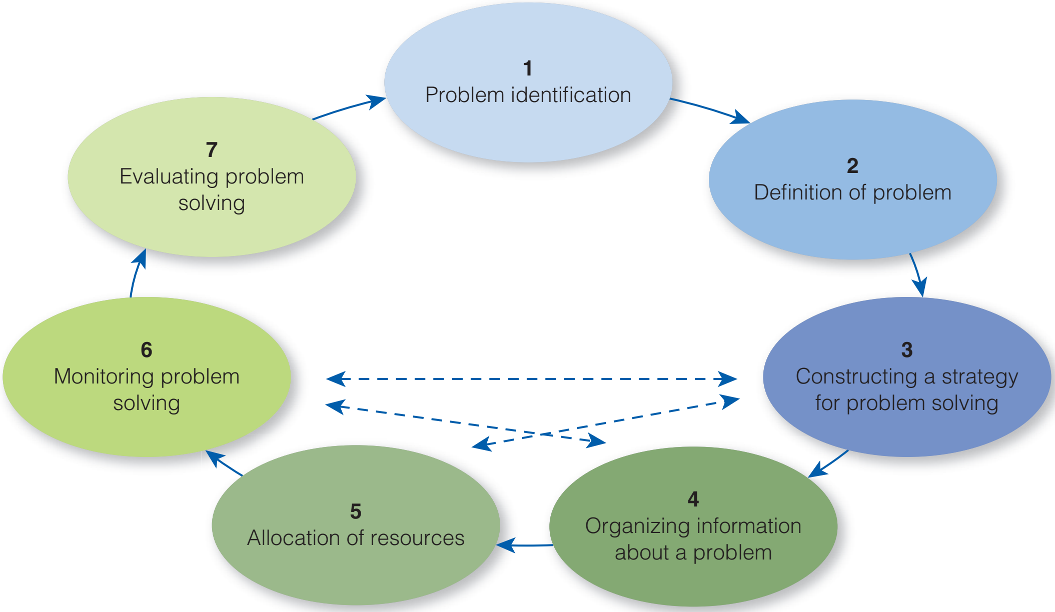
The **problem-solving cycle** includes problem identification, problem definition, strategy formulation, organization of information, allocation of resources, monitoring, and evaluation (shown in Figure 11.2 ■; see Bransford & Stein, 1993; Pretz, Naples, & Sternberg, 2003; Sternberg, 1986).

A description of each part of the problem-solving cycle follows:

1. *Problem identification:* Do we actually have a problem?
2. *Problem definition and representation:* What exactly is our problem?
3. *Strategy formulation:* How can we solve the problem? The strategy may involve **analysis**—breaking down the whole of a complex problem into manageable elements. Instead, or perhaps in addition, it may involve the complementary process of **synthesis**—putting together various elements to arrange them into something useful.

   Another pair of complementary strategies involves divergent and convergent thinking. In **divergent thinking**, you try to generate a diverse assortment of possible alternative solutions to a problem. Once you have considered a variety of possibilities, however, you must engage in **convergent thinking** to narrow down the multiple possibilities to converge on a single best answer.
4. *Organization of information:* How do the various pieces of information in the problem fit together?
5. *Resource allocation:* How much time, effort, and money should I put into this problem?

   Studies show that expert problem solvers (and better students) tend to devote more of their mental resources to global (big-picture) planning than do


1
Problem identification
2
Definition of problem
3
Constructing a strategy for problem solving
4
Organizing information about a problem
5
Allocation of resources
6
Monitoring problem solving
7
Evaluating problem solving

■ **Figure 11.2 The Problem-Solving Cycle.** The steps of the problem-solving cycle include problem identification, problem definition, strategy formulation, organization of information, allocation of resources, monitoring, and evaluation.

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novice problem solvers. Novices (and poorer students) tend to allocate more time to local (detail-oriented) planning than do experts (Larkin et al., 1980; Sternberg, 1981). For example, better students are more likely than poorer students to spend more time in the initial phase, deciding how to solve a problem, and less time actually solving it (Bloom & Broder, 1950). By spending more time in advance deciding what to do, effective students are less likely to fall prey to false starts, winding paths, and all kinds of errors. When a person allocates more mental resources to planning on a large scale, he or she is able to save time and energy and to avoid frustration later on.

6. *Monitoring:* Am I on track as I proceed to solve the problem?
7. *Evaluation:* Did I solve the problem correctly?

In considering the steps, remember also the importance of flexibility in following the various steps of the cycle. Successful problem solving may involve occasionally tolerating some ambiguity regarding how best to proceed. Rarely can we solve problems by following any one optimal sequence of problem-solving steps. We may go back and forth through the steps. We can change their order, or even skip or add steps when it seems appropriate.

Our emotions can influence how we implement the problem-solving cycle (Schwarz & Skurnik, 2003). In groups with participants with high measured emotional intelligence—that is, the ability to identify emotions in others and regulate emotions in oneself—emotional processing can positively influence problem solving (Jordan & Troth, 2004; Zhou, 2013). In mathematicians, the ability to regulate their emotional state (among other factors) is related to higher problem-solving ability (Carlson & Bloom, 2005).

✓ CONCEPT CHECK

1. Why is the process of solving problems described as a cycle?
2. What are the different steps of the problem-solving cycle?

Types of Problems

Problems can be categorized according to whether or not they have clear paths to a solution (Davidson & Sternberg, 1984). **Well-structured problems** have clear paths to solutions. These problems also are termed *well-defined problems.* An example would be, "How do you find the area of a parallelogram?" **Ill-structured problems** lack clear paths to solutions (Shin, Jonassen, & McGee, 2003). These problems are also termed *ill-defined problems.* An example is shown in Figure 11.1: "How do you tie together two suspended strings, when neither string is long enough to allow you to reach the other string while holding either of the strings?" Or how do you decide on which house to buy if each of the potential houses has advantages and disadvantages? Of course, in the real world of problems, these two categories may represent a continuum of clarity in problem solving rather than two discrete classes with a clear boundary between the two. Nonetheless, the categories are useful in understanding how people solve problems. Next, we consider each of these kinds of problems in more detail.

Well-Structured Problems

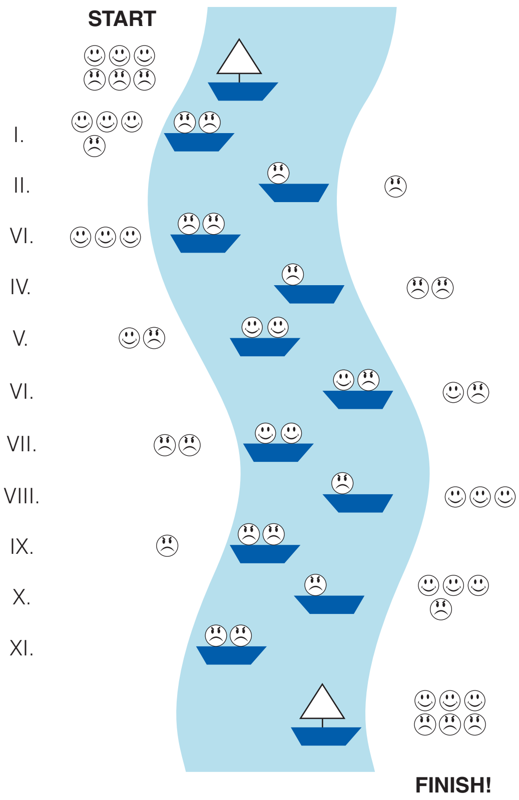
On tests in school, your teachers have asked you to tackle countless well-structured problems in specific content areas (e.g., math, history, geography). These problems had clear paths, if not necessarily easy paths, to their solutions—in particular, the application of a formula. In psychological research, cognitive psychologists might ask you to solve less content-specific kinds of well-structured problems. For example, cognitive psychologists often have studied a particular type of well-structured problem: the class of *move problems,* so termed because such problems require a series of moves to reach a final goal state. Perhaps the most well known of the move problems is one involving two antagonistic parties, whom we call “hobbits” and “orcs,” in the *Investigating Cognitive Psychology: Move Problems* box.

INVESTIGATING COGNITIVE PSYCHOLOGY

Move Problems

Three hobbits and three orcs are on a river bank. The hobbits and orcs need to cross over to the other side of the river. They have for this purpose a small rowboat that will hold just two people. There is one problem, however. If the number of orcs on either river bank exceeds the number of hobbits on that bank, the orcs will eat the hobbits on that bank. How can all six creatures get across to the other side of the river in a way that guarantees that they all arrive there with the forest intact? Try to solve the problem before reading on.

The solution to the problem is shown in Figure 11.3 ■. The solution contains several features worth noting. First, the problem can be solved in a minimum of eleven steps, including the first and last steps. Second, the solution is essentially *linear* in nature. Most steps of the problem solution have just one valid move (connecting two points with a line segment). At all but two steps along the solution path, only one error can be made without violating the rules of the move problem: to go directly backward in the solution. At two steps, there are two possible forward-moving responses. But both of these lead toward the correct answer. Thus, again, the most likely error is to return to a previous state in the solution of the problem.



■ **Figure 11.3 Solution to the Problem of the Hobbits and Orcs.** How can you get both the hobbits and the orcs to the other side of the river without any hobbits getting eaten? What can you learn about your own methods of solving problems by seeing how you approached this particular problem?

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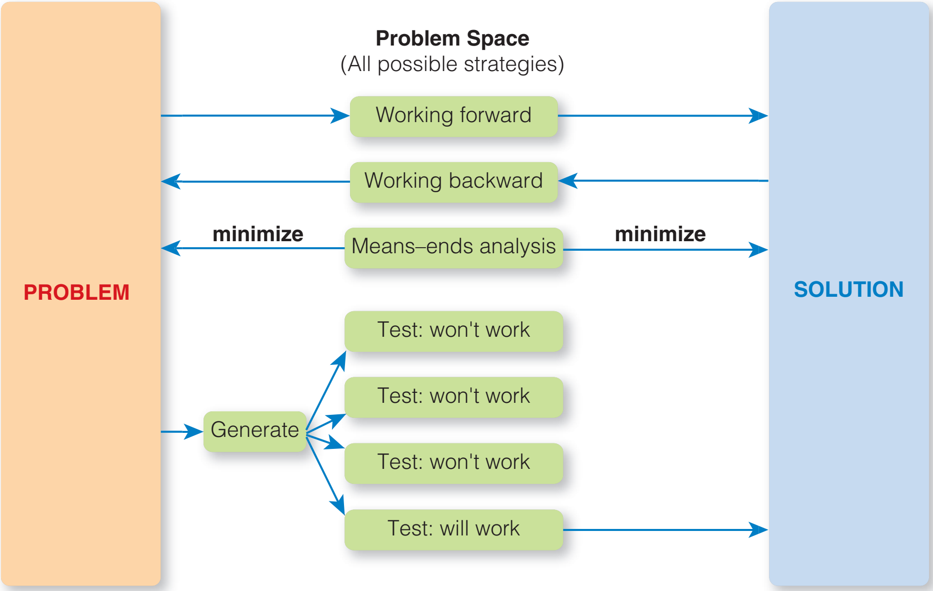
People seem to make three main kinds of errors when trying to solve well-structured problems (Greeno, 1974; Simon & Reed, 1976; Thomas, 1974). These errors are as follows:

1. *Inadvertently moving backward*: They revert to a state that is further from the end goal, for instance, moving all of the "orcs" and "hobbits" back to the first side of the river.
2. *Making illegal moves*: They make an illegal move—that is, a move that is not permitted according to the terms of the problem. For example, a move that resulted in having more than two individuals in the boat would be illegal.
3. *Not realizing the nature of the next legal move*: They become "stuck"—they do not know what to do next, given the current stage of the problem. An example would be realizing that you must bring one "orc" or "hobbit" back across the river to its starting point before you can move any of the remaining characters.

One method researchers use to study how to solve well-defined problems is to develop computer simulations. Here, the researcher's task is to create a computer program that can solve these problems. By developing the instructions a computer must execute to solve problems, the researcher may better understand how humans solve similar kinds of problems. According to one model of problem solving, the problem solver (which may be using human or artificial intelligence) must view the initial problem state and the goal state within a problem space (Wenke & Frensch, 2003). A **problem space** is the universe of all possible actions that can be applied to solving a problem, given any constraints that apply to the solution of the problem. Figure 11.4 ■ shows a general problem space for the move problem. It illustrates that any number of possible strategies can solve it.

Algorithms are sets of procedures (in a problem space) that may be repeated over and over again and that, in theory, guarantee the solution to a problem (Hunt, 1975; Sternberg, 2000). Generally, an algorithm continues until it satisfies a condition determined by a program. Suppose a computer is provided with a well-defined problem and an appropriate hierarchy (program) of operations organized into procedural algorithms. The computer can readily calculate all possible operations and combinations of operations within the problem space. It also can determine the best possible sequence of steps to take to solve the problem.



■ **Figure 11.4 Problem Space.** A problem space contains all the possible strategies leading from the initial problem state to the solution (the goal state). This problem space, for example, shows four of the heuristics that might be used in solving the move problem illustrated in Figure 11.3.

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Unlike computers, however, the human mind does not specialize in high-speed computations of numerous possible combinations. The limits of our working memory prohibit us from considering more than just a few possible operations at one time (Hambrick & Engle, 2003; Kintsch et al., 1999; see also Chapter 5). Newell and Simon (1972) recognized these limits and observed that humans must use mental shortcuts to solve problems. These mental shortcuts are termed **heuristics**—informal, intuitive, speculative strategies that sometimes lead to an effective solution and sometimes do not (see Chapter 12 for more on heuristics; Gilovich, Griffin, & Kahneman, 2002; Stanovich, 2003; Sternberg, 2000). For example, most people think that the likelihood is higher of someone being killed by a shark than by falling airplane parts. This is because shark attacks are more widely publicized than deaths that occur because of falling airplane parts. Thus, we can recall with more ease the cases in which someone has been killed by a shark: We have this information more readily available, which is why the heuristic we are using here is called the *availability heuristic*. But in fact, we are about 30 times more likely to be killed by falling airplane parts than by a shark attack.

Suppose we store, in long-term memory, several simple heuristics that we can apply to a variety of problems. We thereby can lessen the burden on our limited-capacity working memory. Studies suggest that when problem solvers are confronted with a problem for which they cannot immediately see an answer, effective problem solvers use the heuristic of means–ends analysis. In this strategy, the problem solver continually compares the current state and the goal state and takes steps to minimize the differences between the two states. Various other problem-solving heuristics include *working forward, working backward,* and *generate and test.* Table 11.1 ■ illustrates how a problem solver might

Table 11.1 **Four Heuristics**

These four heuristics may be used to solve the move problem illustrated in Figure 11.3.

Heuristic	Definition of Heuristic	Heuristic Applied to the Hobbit–Orc Move Problem (Greeno & Simon, 1988)	Heuristic Applied to an Everyday Problem: How to Fly Using the Most Direct Route (Hunt, 1994)
Means–ends analysis	Solving the problem by decreasing the distance between the current position in the problem space and the end goal in that space.	Try to get as many individuals on the far bank and as few people on the near bank as possible.	Try to minimize the distance between home and the destination.
Working forward	Start at the beginning and attempt to solve the problem from the start to the finish.	Evaluate the situation carefully with the six people on one bank and then try to move them step by step to the opposite bank.	Find the possible air routes leading from home toward the destination, and take the routes that seem most directly to lead to the destination.
Working backward	Start at the end and attempt to work backward from there.	Start with the final state—having all hobbits and all orcs on the far bank—and try to work back to the beginning state.	Find the possible air routes that reach the destination, and work backward to trace which of these routes are most direct from origin.
Generate and test	Generate alternative courses of action, not necessarily in a systematic way, and note whether each course of action will work.	There is only one allowable forward move, and there are never more than two possibilities, both of which eventually will lead to the solution.	Find the alternative routes from origin; then determine which to use to reach the destination. Choose the most direct route. Given the high number of possible combinations of routes for air travel, this heuristic may not be very helpful.

apply these heuristics to the aforementioned move problem (Greeno & Simon, 1988) and to a more common everyday problem (Hunt, 1994). We also will apply these concepts to the Tower of Hanoi problem later in this chapter.

Isomorphic Problems

Sometimes, two problems are **isomorphic**—that is, their formal structure is the same, and only their content differs. For example, the hobbits and orcs problem is similar to the missionaries and cannibals problem, in which cannibals eat missionaries when they outnumber them. In this example, the isomorphism is obvious. Similarly, you can readily detect the isomorphism of many games, such as Scrabble and Boggle, that involve constructing words from jumbled or scrambled letters.

Determining the underlying structural isomorphism of problems is often difficult. It is also difficult to apply problem-solving strategies from one problem to another. For example, it may not be clear how an example from a textbook applies to another problem on a test. Problem solvers are particularly unlikely to detect isomorphisms when two problems are similar but not identical in structure. Furthermore, when the content or the surface characteristics of the problems differ sharply, detecting the isomorphism of the structure of problems is harder. For example, school-aged children may find it difficult to see the structural similarity between various word problems that are framed within different story situations. Similarly, physics students may have difficulty seeing the structural similarities among various physics problems when different kinds of materials are used. The problem of recognizing isomorphisms across varying contexts returns us to the recurring difficulties in problem representation.

Problem Representation Does Matter

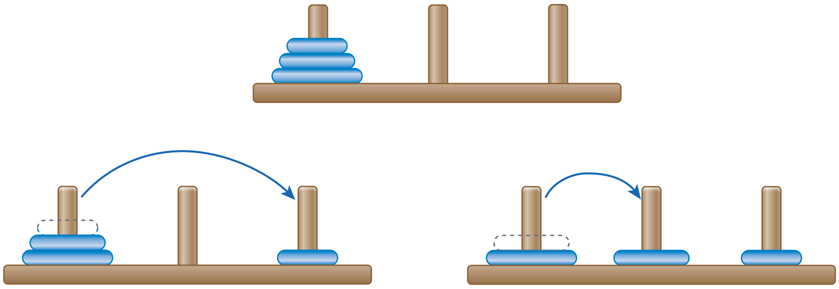
What is the key reason that some problems are easier to solve than others that are isomorphic to them? Consider the various versions of a problem known as the *Tower of Hanoi*. In this problem, the problem solver must use a series of moves to transfer a set of rings (usually three) from the first of three pegs to the third of the three pegs, using as few moves as possible (see Figure 11.5 ■). As you move the rings from one peg to another, three rules apply:

1. You may move only one disc at a time.
2. You may move a disc only when there is no disc on top of it.
3. You never may move a larger disc on top of a smaller one.

Several electronic versions of the Tower of Hanoi are available online. You can find them by entering the search words "Tower of Hanoi game" in a search engine. Try it out yourself!

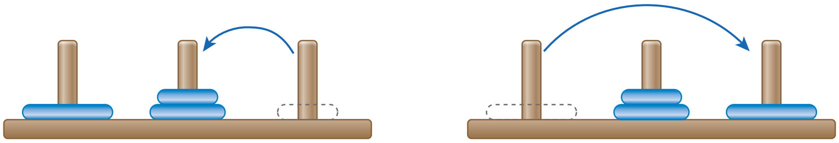
If you have tried to solve the problem yourself, you will have noticed that there was not just one step from the initial state to the goal state—you had to go through a number of steps, each of which represented an *intermediate state*. To return to our previous discussion, the problem space includes the initial state, the goal state, and all possible intermediate states. Figure 11.5(b) shows the problem space for the Tower of Hanoi problem.

Researchers presented this same basic problem in many different isomorphic forms, for example, as dots that have to be transferred between boxes (Kotovsky, Hayes, & Simon, 1985). They found that some forms of the problem took up to 16 times as long to solve as other forms. Although many factors influenced these findings, a major determinant of the relative ease of solving the problem was how the problem was represented. For example, in the form shown in Figure 11.5, the physically different sizes of the discs facilitated the mental representation of the restriction against moving larger discs onto smaller discs. Other forms of the problem did not. Many variations of this task involve differing rules and restrictions (Chen, Tian, & Wang, 2007).



(a)

Subgoal 1: Free up large disc.
(b)



Subgoal 2: Free up third peg.
(c)

Subgoal 3: Move large disc onto third peg.
(d)

■ **Figure 11.5** **The Tower of Hanoi.** There are three discs of unequal sizes, positioned on the far-left side of three pegs so that the largest disc is at the bottom, the midsize disc is in the middle, and the smallest disc is on the top. Your task is to transfer all three discs to the peg on the far right, using the middle peg as a stationing area as needed. You may move only one disc at a time, and you may never move a larger disc on top of a smaller disc. The problem space for the Tower of Hanoi problem comprises the initial state, the goal state, and all possible moves (intermediate states) that can be executed to get from initial state to goal state.

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Problems like the Tower of Hanoi challenge problem-solving skills, in part through their demands on working memory. Studies indicate a relationship between working-memory capacity and the ability to solve analytic problems (Fleck, 2007; Trezise & Reeve, 2014). Other researchers had experimental participants do what they called the *Tower of London task*, which is very similar to the Tower of Hanoi (Welsh, Satterlee-Cartmell, & Stine, 1999). In this task, the goal was to move a set of colored balls with holes in the middle of them across different-sized pegs to match a target configuration. As in the Tower of Hanoi, there were constraints on which balls could be moved at a given time. The researchers also gave participants two tests of working-memory capacity. They found that the measures of working-memory capacity accounted for between 25% and 36% of the variance in how successful participants were in solving the problem. Interestingly, mental-processing speed, sometimes touted as a key to intelligence, showed no correlation with success in solution. The brain areas that seem most involved in the Tower of London task are the prefrontal cortex, bilateral parietal cortex, and bilateral premotor cortex (Fincham et al., 2002).

Recall the two-string problem, posed at the outset of this chapter. The solution to the two-string problem is shown in Figure 11.6 ■. Many people find it extremely difficult to solve this problem. Many never do, no matter how hard they try. People who find the problem insoluble often err at Step 2 of the problem-solving cycle (definition of the problem): They define the problem as one in which they must be able to move toward one string while holding another; they impose on themselves a constraint that makes the problem virtually insoluble.

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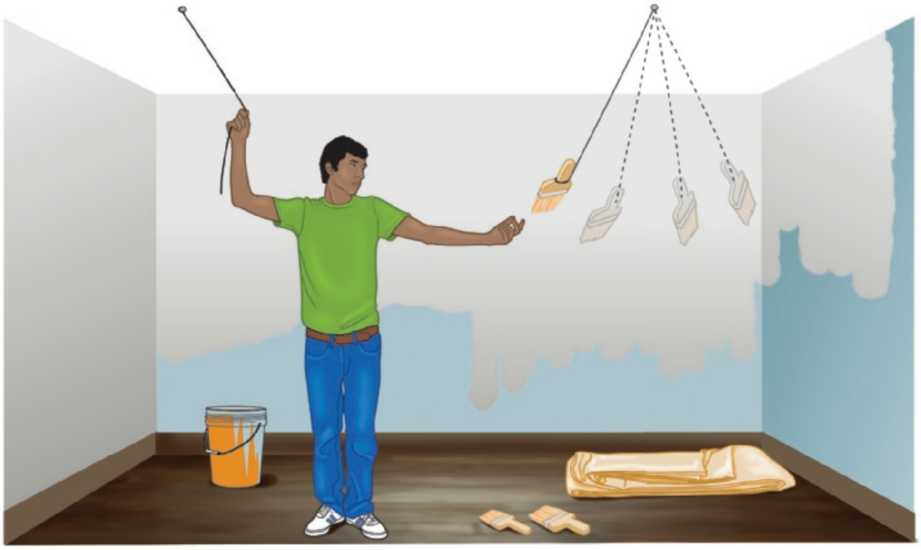

■ **Figure 11.6 Solution to the String Problem.** Many people assume that they must find a way to move themselves toward each string and then bring the two strings together. They fail to consider the possibility of finding a way to get one of the strings to move toward them, such as by tying something to one of the strings, then swinging the object as a pendulum, and grabbing the object when it swings close to the other string. Nothing in the problem suggests that the person, rather than the string, must move. Nevertheless, most people presuppose that the constraint exists. By placing an unnecessary and unwarranted constraint on themselves, people make the problem insoluble.

Source: Based on Richard E. Mayer, "The Search for Insight: Grappling with Gestalt Psychology's Unanswered Questions," in *The Nature of Insight,* edited by R. J. Sternberg and J. E. Davidson. Copyright © 1995 by MIT Press.

Ill-Structured Problems and the Role of Insight

The two-string problem is an example of an ill-structured problem. In fact, although we occasionally may misrepresent well-structured problems, we are much more likely to have difficulty representing ill-structured problems. Before we explain the nature of ill-structured problems, try to solve a few more of these problems. The following illustrate some of the difficulties of representing ill-structured problems (after Sternberg, 1986). Be sure to try all three problems before you read about their solutions.

1. Haughty Harry has been asked to build a hat rack with a few given materials (see Figure 11.7 ■). Can you help him construct the hat rack?
2. A woman who lived in a small town married 20 different men in that same town. All of them are still living, and she never divorced any of them. Yet she broke no laws. How could she do this?
3. You have loose black and brown socks in a drawer, mixed in a ratio of five black socks for every brown one. How many socks do you have to take out of that drawer to be assured of having a pair of the same color?

Both the two-string problem and each of the three preceding problems are ill-structured problems. There are no clear, readily available paths to a solution. By definition, ill-structured problems do not have well-defined problem spaces. Problem solvers have difficulty constructing appropriate mental representations for modeling these problems and their solutions. For such problems, much of the difficulty is in constructing a

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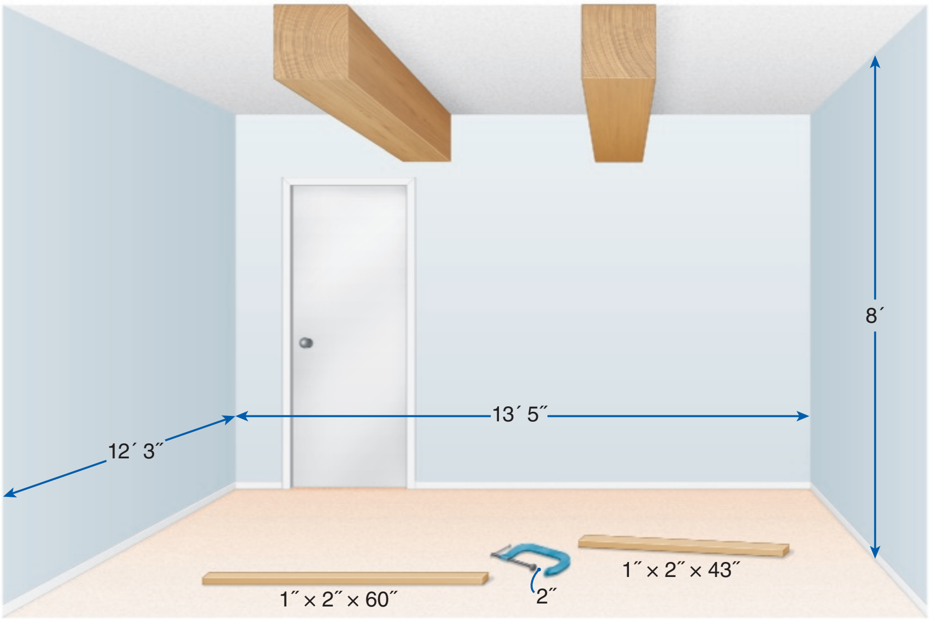

Figure 11.7 Haughty Harry's Problem. Haughty Harry and several other job seekers were looking for work as carpenters. The site supervisor handed each applicant two sticks (a 1˝ × 2˝ × 60˝ stick and a 1˝ × 2˝ × 43˝ stick) and a 2˝ C-clamp. The opening of the clamp is wide enough so that both sticks can be inserted and held together securely when the clamp is tightened. The supervisor ushered the job applicants into a room 12´ 3˝ × 13´ 5˝ with an 8´ ceiling. Mounted on the ceiling were two 1´ × 1´ beams, dividing the ceiling into thirds lengthwise. The supervisor told the applicants that she would hire the first applicant who could build a hat rack capable of supporting her hard hat, using just the two sticks and the C-clamp. She could hire only one person. So she recommended that the applicants not try to help one another. What should Harry do?

Source: Based on Richard E. Mayer, "The Search for Insight: Grappling with Gestalt Psychology's Unanswered Questions," in *The Nature of Insight,* edited by R. J. Sternberg and J. E. Davidson. Copyright © 1995 MIT Press.

plan for sequentially following a series of steps that inch ever closer to their solution. In one study, both domain knowledge and justification skills proved to be important for solving both ill- and well-structured problems. Justification skills are important because ill-structured problems can be represented in different ways and often have alternative solutions. Thus, problem solvers need to choose and justify their selection of a particular representation and solution. Additional cognitive and affective factors, including attitudes toward science and regulation of cognition, are also important for solving ill-structured problems (Shin, Jonassen, & McGee, 2003).

The preceding ill-structured problems are *insight problems* because you need to see the problem in a novel way. In particular, you need to see it differently from how you would probably see the problem at first, and differently from how you would probably solve problems in general. That is, you must restructure your representation of the problem to solve it.

Insight is a distinctive and sometimes seemingly sudden understanding of a problem or of a strategy that aids in solving the problem. Often, an insight involves reconceptualizing a problem or a strategy in a totally new way. Insight often involves detecting and combining relevant old and new information to gain a novel view of the problem or of its solution. Although insights may feel as though they are sudden, they are often the result of much prior thought and hard work. Without this work, the insight never would

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have occurred. Insight can be involved in solving well-structured problems, but it more often is associated with the rocky and twisting path to solution that characterizes ill-structured problems. For many years, psychologists interested in problem solving have been trying to figure out the true nature of insight.

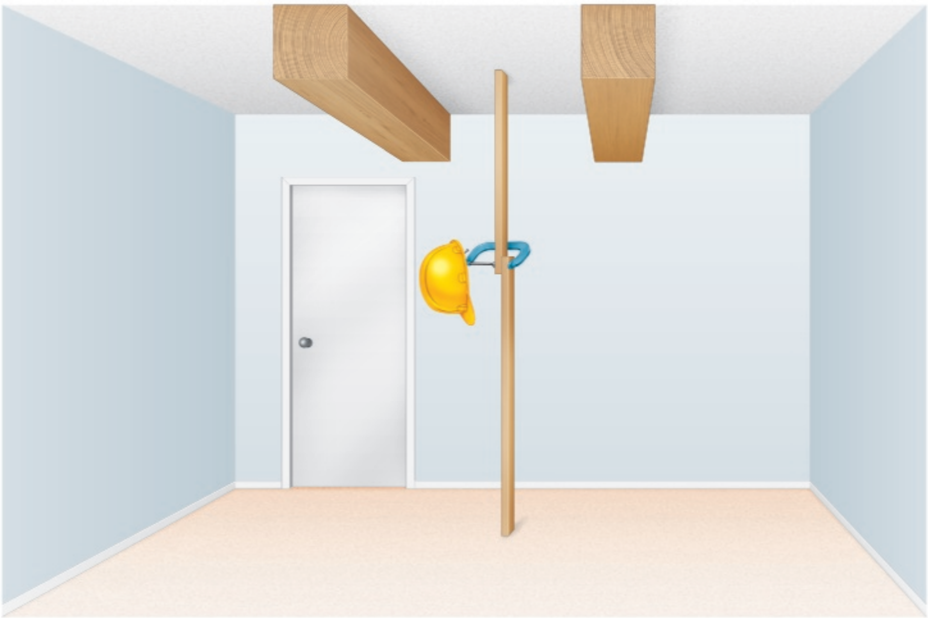
What are the solutions to the insight problems we presented? Consider first the hat-rack problem. Harry was unable to solve the problem before Sally quickly whipped together a hat rack like the one shown in Figure 11.8 ■. To solve the problem, Sally had to redefine her view of the materials in a way that allowed her to conceive of a C-clamp as a hat holder.

The woman who was involved in multiple marriages is a minister. The critical element for solving this problem is to recognize that the word *married* may be used to describe the performance of the marriage ceremony. So the minister married the 20 men but did not herself become wedded to any of them. To solve this problem, you had to redefine your interpretation of the term *married.* Others have suggested yet additional possibilities. For example, perhaps the woman was an actress and only married the men in her role as an actress. Or perhaps the woman's multiple marriages were annulled so she never technically divorced any of the men.

As for the socks, you need only to take out three socks to be assured of having a pair of the same color. The ratio information is irrelevant. Whether the first two socks you withdraw match in color, the third certainly will match at least one of the first two.

Early Gestaltist Views

Gestalt psychologists emphasized the importance of the whole as more than a collection of parts. In regard to problem solving, Gestalt psychologists held that insight problems require problem solvers to perceive the problem as a whole. Gestalt psychologist Max Wertheimer (1945/1959) wrote about **productive thinking**, which involves insights that go beyond the bounds of existing associations. He distinguished productive thinking from *reproductive thinking,* which is based on existing associations involving what is already known. According to Wertheimer, insightful (productive) thinking differs fundamentally from reproductive thinking. In solving the insight problems given in this



■ **Figure 11.8 Solution to Haughty Harry's Problem.** Were you able to modify your definition of the materials available in a way that helped you solve the problem?

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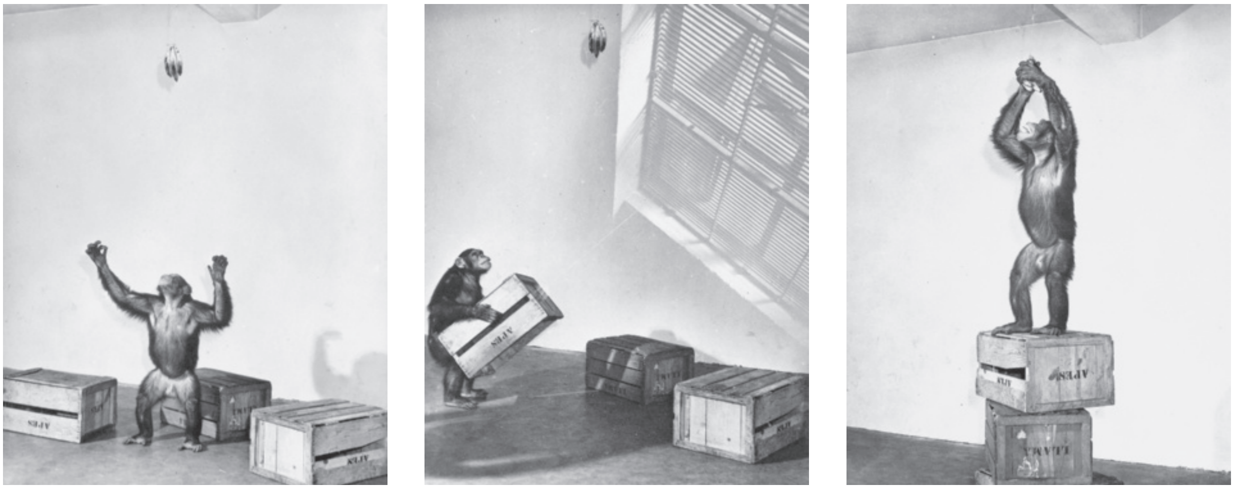
chapter, you had to break away from your existing associations and see each problem in an entirely new light. Productive thinking also can be applied to well-structured problems.

Wertheimer's colleague Wolfgang Köhler (1927) studied insight in nonhuman primates, particularly a caged chimpanzee named Sultan. In Köhler's view, the ape's behavior illustrated insight (see Figure 11.9 ■). To Köhler and other Gestaltists, insight is a special process. It involves thinking that differs from normal, linear information processing.

The Neo-Gestaltist View

Some researchers have found that insightful problem solving can be distinguished from noninsightful problem solving in two ways (Metcalfe, 1986; Metcalfe & Wiebe, 1987). First, when given routine problems to solve, problem solvers show remarkable accuracy in their ability to predict their own success in solving a problem before any attempt to solve it. Second, when given insight problems, problem solvers show poor ability to predict their own success before trying to solve the problems. Not only were successful problem solvers pessimistic about their ability to solve insight problems, but unsuccessful problem solvers were often optimistic about their ability to solve them.

In addition, the investigators used a clever methodology to observe the problem-solving process while participants were solving routine versus insight problems. Routine problems included algebra problems, such as $(3x^2 + 2x + 10)(3x) =$. Insight problems included problems such as "A prisoner was attempting escape from a tower. He found in his cell a rope that was half the length needed to permit him to reach the ground safely. He divided the rope in half and tied the two parts together and escaped. How could he have done this?" At 15-second intervals, participants paused briefly to rate how close ("warm") versus far ("cold") they felt they were to reaching a solution. Consider first what happened for routine problems, such as algebra, or the Tower of Hanoi. Participants showed increases in their feelings of warmth as they drew closer to reaching a correct solution. For insight problems, however, participants showed no such increases. Figure 11.10 ■ shows



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■ **Figure 11.9** **Insight Demonstrated by Chimpanzee.** Gestalt psychologist Wolfgang Köhler placed an ape in an enclosure with a few boxes. At the top of the cage, just out of reach, was a bunch of bananas. After the ape unsuccessfully tried to jump and to stretch to reach the bananas, the ape showed sudden insight: The ape realized that the boxes could be stacked on top of one another to make a structure tall enough to reach the bunch of bananas.

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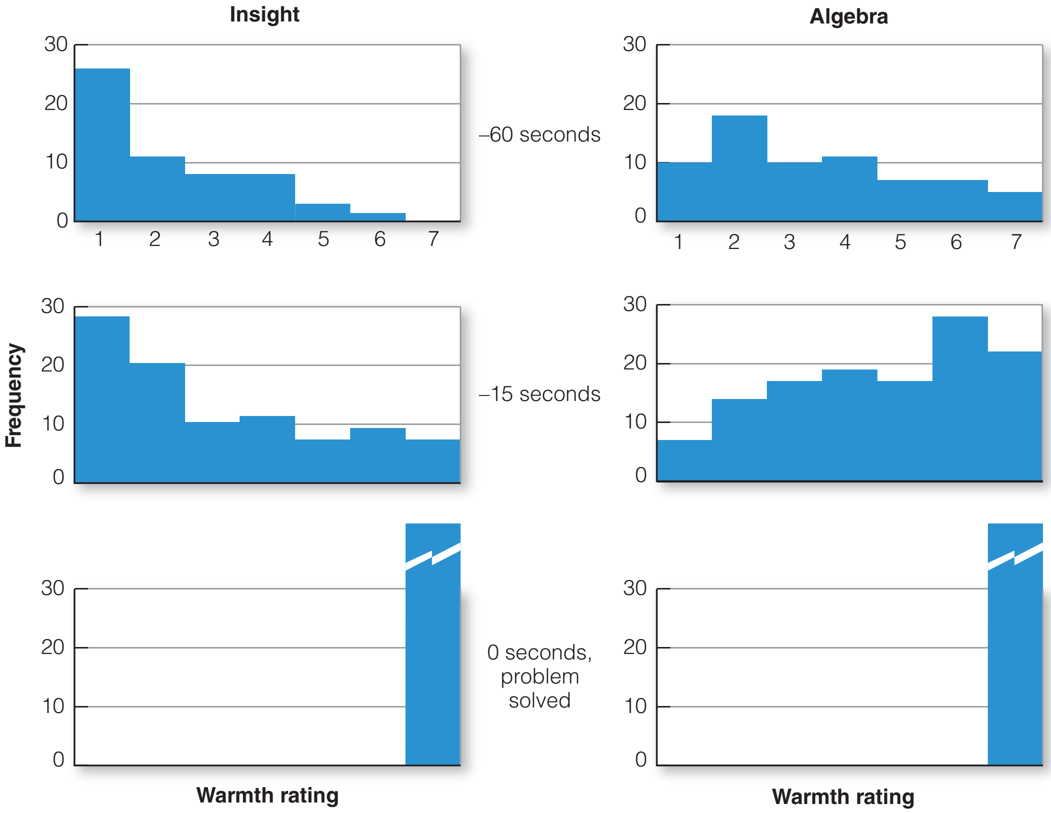

Figure 11.10 **Feelings of Warmth in Insightful Problem Solving.** When Janet Metcalfe presented her participants with routine problems and insight problems, they showed clear differences in their feelings of warmth as they approached a solution to the problems. Warmth was rated on a scale from 1 to 7. The frequency histograms show you how often participants gave a particular rating of warmth 60 seconds and 15 seconds before solving the problem. As you can see, for insight problems the graphs look relatively similar. Most people rated their feeling of warmth with a 1, and only a few people rated warmth highly. For a routine algebra problem, however, many more participants rated their feelings of warmth highly when they were close to the solution as compared with one minute before the solution. Once the problem was solved, everybody rated their feelings of warmth with a 7.

Source: Based on Metcalfe, J., & Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Memory & Cognition*, 15(3), 238–246. pp. 242, 245.

a comparison of participants' reported feelings of warmth for solving algebra problems versus insight problems. In solving insight problems, participants showed no increasing feelings of warmth until moments before abruptly realizing the solution and correctly solving the problem. Metcalfe's findings certainly seem to support the Gestaltist view that something special pertains to insightful problem solving, as distinct from noninsightful, routine problem solving. The specific nature and underlying mechanisms of insightful problem solving have yet to be addressed by this research, however.

Insights into Insight

Insights need not be sudden "a-ha" experiences, according to Smith (1995). They may and often do occur gradually and incrementally over time. When an insightful solution is needed but not forthcoming, sleep may help produce a solution. In both mathematical problem solving and solving a task that requires understanding rules, sleep has been shown to increase the likelihood that an insight will be produced (Stickgold & Walker, 2004; Wagner et al., 2004).

Unfortunately, insights—like many other aspects of human thinking—can be both startlingly brilliant and dead wrong. How do we fall into mental traps that lead us down false paths as we try to reach solutions?

Neuroscience and Insight

Neuroimaging studies suggest that the activity of our brain during rest can be divided up into several different networks. Some of these networks are also active when we engage in problem solving. This activity indicates that at least portions of the thought processes are the same when we are problem solving and when we have thoughts during rest (Andreasen et al., 1995; Christoff, Ream, & Gabrieli, 2004 2004; Damoiseaux et al., 2006; Kounios et al., 2008). Functional magnetic resonance imaging (fMRI) studies show that activity in the right anterior superior-temporal gyrus increases when a person experiences an insight. Furthermore, electroencephalograms (EEGs) also record a burst of high-frequency activity during insight (Jung-Beeman et al., 2004). In fact, before insights even become conscious, activity in the right hemisphere can be observed. It is therefore generally assumed that the right hemisphere has a special role in insight processes.

The right hippocampus is critical in the formation of an insightful solution (Luo & Niki, 2003). (As you may remember from Chapters 2 and 5, the hippocampus is integral to the formation of new memories. Therefore, it makes sense that the hippocampus would be involved in the formation of an insightful solution, as this process involves combining relevant information stored in memory.) Another study demonstrated a spike of activity in the right anterior temporal area immediately before an insight is formed. This area is active during all types of problem solving, as it involves making connections among distantly related items (Jung-Beeman et al., 2004). This spike in activity, however, suggests a sudden understanding of relationships within a problem that leads to a solution.

Neural correlates measured even before an individual sees a problem can predict whether insight will occur. In one study, during the preparation before viewing a problem, participants who would later generate an insightful solution had substantial activation in the frontal lobes, whereas those who would not generate an insightful solution had comparable activation in the occipital lobes (Kounios et al., 2006). These findings suggest, first, that certain problem solvers are more likely to use insight than others. Second, they suggest that insight involves some planning that occurs before a problem is even presented.

CONCEPT CHECK

1. What is the difference between well-structured and ill-structured problems?
2. When are two problems isomorphic?
3. What is insight?
4. According to Neo-Gestaltism, how can insightful problem solving and non-insightful problem solving be distinguished?
5. Are insights always sudden?

Obstacles and Aids to Problem Solving

Several factors can hinder or enhance problem solving. Among them are mental sets as well as positive and negative transfer. Incubation plays a role in problem solving as well. In the next sections, we will explore these factors in more detail.

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Mental Sets, Entrenchment, and Fixation

One factor that can hinder problem solving is **mental set**—a frame of mind involving an existing model for representing a problem, a problem context, or a procedure for problem solving. Another term for mental set is *entrenchment.* When problem solvers have an entrenched mental set, they fixate on a strategy that normally works well in solving many problems but that does not work well in solving this particular problem. For example, in the two-string problem, you may fixate on strategies that involve moving yourself toward the string, rather than moving the string toward you. In the oft-marrying minister problem, you may fixate on the notion that to marry someone is to become wedded to the person.

Mental sets also can influence the solution of routine problems. For example, consider water-jar problems (Luchins, 1942). In water-jar problems, participants are asked how to measure out a certain amount of water using three different jars. Each jar holds a different amount of water. *Investigating Cognitive Psychology: Luchin's Water-Jar Problems* shows the problems used by Luchins. Look at the box and try to solve the problems yourself before you read on.

INVESTIGATING COGNITIVE PSYCHOLOGY

Luchins's Water-Jar Problems

How do you measure out the right amount of water using Jars A, B, and C? You need to use up to three jars to obtain the required amounts of water (measured in numbers of cups) in the last column. Columns A, B, and C show the capacity of each jar. The first problem, for example, requires you to get 20 cups of water from just two of the jars, a 29-cup one (Jar A) and a 3-cup one (Jar B). Easy: Just fill Jar A, and then empty out 9 cups from this jar by taking out 3 cups three times, using Jar B. Problem 2 isn't too hard, either. Fill Jar B with 127 cups, then empty out 21 cups using Jar A, and then empty out 6 cups, using Jar C twice. Now try the rest of the problems yourself. (After Luchins, 1942.)

Jars Available for Use				
Problem Number	**A**	**B**	**C**	**Required Amount (CUPS)**
1	29	3	0	20
2	21	127	3	100
3	14	163	25	99
4	18	43	10	5
5	9	42	6	21
6	20	59	4	31
7	23	49	3	20
8	15	39	3	18
9	28	76	3	25
10	18	48	4	22
11	14	36	8	6

Source: Luchins, Abraham S. (1942). Mechanization in problem solving: The effect of Einstellung, *Psychological Monographs*, 54(6), 248. © 1942, by Dr. Abraham S. Luchins.

If you are like many people solving these problems, you will have found a formula that works for all the remaining problems after problem #1. You fill up Jar B. Then you pour out of it the amount of water you can put into Jar A. Then you twice pour out of it the amount of water you can put into Jar C. The formula, therefore, is B – A – 2C.

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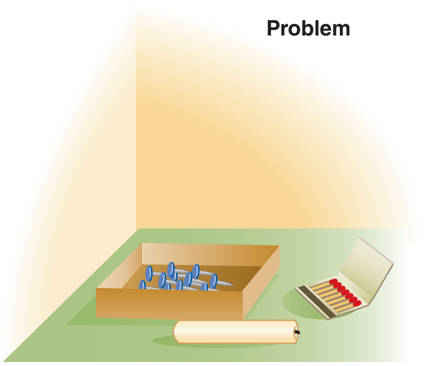
Problems 7 through 11 can be solved in a much simpler way. One need use just two of the jars. Problem 7 can be solved by A – C. Problem 8 can be solved by A + C, and so on. People who are given Problems 1 through 6 to solve generally continue to use the B – A – 2C formula in solving Problems 7 through 11. Consider, in Luchins's original experiment, those participants who solved the first set of problems. Between 64% and 83% of participants went on to solve the last set of problems by using the harder strategy. What happened to the control participants who were not given the first set of problems? Only 1% to 5% failed to apply the simpler solutions to the last set of problems. They had no established mental set that interfered with their seeing things in a new and simpler way.

Another type of mental set involves fixation on a particular use (function) for an object. Specifically, **functional fixedness** is the inability to realize that something known to have a particular use also may be used to perform other functions (German & Barrett, 2005; Rakoczy, Warneken, & Tomasello, 2009). Functional fixedness prevents us from solving new problems by using old tools in novel ways. Becoming free of functional fixedness is what first allowed people to use a reshaped coat hanger to get into a locked car. It is also what first allowed thieves to pick simple spring door locks with a credit card. One well-known example of functional fixedness is Karl Duncker's candle problem (1947). Subjects are presented with some candles, a box of matches, and some tacks. Their task is to affix a candle to the wall so that the wax from the burning candle will not drip on the floor (see Figure 11.11 ■). Can you solve the problem before checking the answer on the next page? Duncker presented the materials for this experiment either in small cardboard containers, or he presented them outside the boxes (so that the boxes were empty). He found that participants who had received the materials inside the boxes were less likely to solve the problem.

Another type of mental set is considered an aspect of social cognition. **Stereotypes** are beliefs that members of a social group tend more or less uniformly to have particular types of characteristics. We seem to learn many stereotypes during childhood. For example, cross-cultural studies of children show their increasing knowledge about—and use of—gender stereotypes across the childhood years (Neto, Williams, & Widner, 1991; Seguino, 2007). Stereotype awareness, for a variety of groups, develops in most children between the ages of 6 and 10 (McKown & Weinstein, 2003). Stereotypes often arise in the same way that other kinds of mental sets develop. We observe a particular instance or set of instances of some pattern. We then may overgeneralize from those limited observations. We may assume that all future instances similarly will demonstrate that pattern. For example, we may observe that some African Americans can run very fast. If we then conclude that every African American is a fast runner, we have a stereotype because not every African American is a fast runner. Of course, when the stereotypes are used to target particular scapegoats for societal mistreatment, grave social consequences result for the targets of stereotypes. The targets are not the only ones to suffer from stereotypes, however. Like other kinds of mental sets, stereotypes hinder the problem-solving abilities of the individuals who used them. These people limit their thinking by using set stereotypes. Being aware of stereotypes about their group also can limit people's performance when they expect to be evaluated. This is called *stereotype threat*. Take, for example, the common prejudice that boys perform better in math than girls. Just being aware of that prejudice in testing situations can make girls perform at a lower level (Tempel & Neumann, 2014). It works the same way with ethnicity: Black participants who indicated their ethnicity before a verbal-ability test



■ **Figure 11.11a Duncker's Candle Problem** How do you affix the candle to the wall so that its wax will not drip on the floor?

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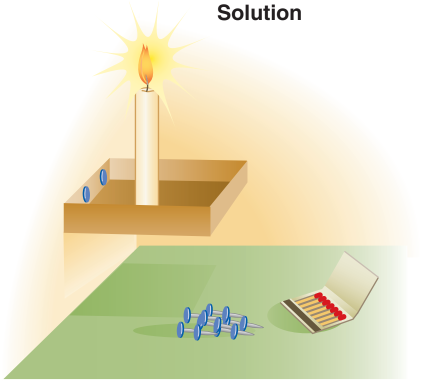
performed worse than their peers who did not indicate their ethnicity (Steele & Aronson, 1995).

Negative and Positive Transfer

Often, people have particular mental sets that prompt them to fixate on one aspect of a problem or one strategy for problem solving to the exclusion of other possible relevant ones. They are carrying knowledge and strategies for solving one kind of problem to a different kind of problem. **Transfer** is any carryover of knowledge or skills from one problem situation to another (Detterman & Sternberg, 1993; Gentile, 2000). Transfer can be either negative or positive. **Negative transfer** occurs when solving an earlier problem makes it harder to solve a later one. Sometimes an early problem gets an



■ **Figure 11.11b Dunker's Candle Solution**

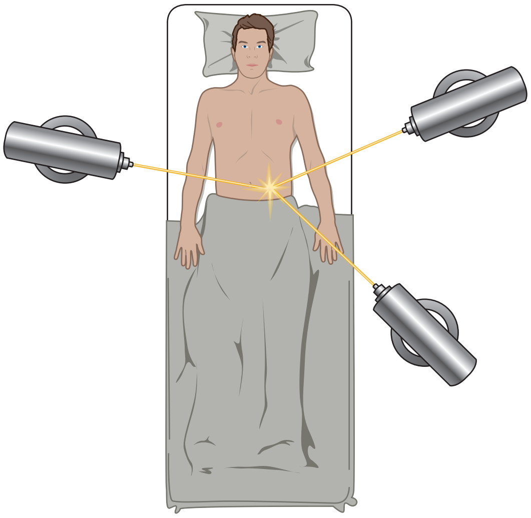
INVESTIGATING COGNITIVE PSYCHOLOGY

Problems Involving Transfer

Imagine that you are a doctor treating a patient with a malignant stomach tumor. You cannot operate on the patient because of the severity of the cancer. But unless you destroy the tumor somehow, the patient will die. You could use high-intensity X-rays to destroy the tumor. Unfortunately, the intensity of X-rays needed to destroy the tumor also will destroy healthy tissue through which the rays must pass. X-rays of lesser intensity will spare the healthy tissue, but they will be insufficiently powerful to destroy the tumor. What kind of procedure could you employ that will destroy the tumor without also destroying the healthy tissue surrounding the tumor?

Duncker had a particular insightful solution in mind as the best one for this problem. Figure 11.12 ■ shows the solution pictorially.

Before presenting Duncker's radiation problem, participants received another, easier problem. This particular problem was called the "military problem" (Holyoak, 1984, p. 205).



■ **Figure 11.12 The Radiation Problem.** The solution to the X-ray problem involving the treatment of a patient with a tumor involves dispersion. The idea is to direct weak X-radiation toward the tumor from a number of different points outside the body. No single set of rays would be strong enough to destroy either the healthy tissue or the tumor. However, the rays would be aimed so that they all converged at one spot within the body—the spot that houses the tumor. This solution actually is used today in some X-ray treatments, except that a rotating source of X-rays is used to disperse rays.

Source: Based on *In Search of the Human Mind*, by Robert J. Sternberg. Copyright © 1995 by Harcourt Brace & Company.

The Military Problem

A general wishes to capture a fortress located in the center of a country. There are many roads radiating outward from the fortress. All have been mined. Although small groups of men can pass over the roads safely, any large force will detonate the mines. A full-scale direct attack is therefore impossible. What should the general do?

Think about this: What are the commonalities between the two problems, and what is an elemental strategy that can be derived by comparing the two problems?

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individual on a wrong track. For example, police may have difficulty solving a political crime because such a crime differs so much from the kinds of crime that they typically deal with. Or when presented with a new tool, a person may operate it in a way similar to the way in which he or she operated a tool with which he or she was already familiar (Besnard & Cacitti, 2005). **Positive transfer** occurs when the solution of an earlier problem makes it easier to solve a new problem. That is, sometimes the transfer of a mental set can be an aid to problem solving. For instance, one may transfer early math skills, such as addition, to advanced math problems of the kinds found in algebra or physics (Bassok & Holyoak, 1989; Chen & Daehler, 1989; see also Campbell & Robert, 2008).

Transfer of Analogies

Analogies often help solve problems. When people think back to other problems they have encountered and solved, they may ask themselves whether the new problem is somehow similar to other ones they previously solved. If they find a relationship, they may have a starting point to solve the new problem. This process is called *analogical problem solving*.

Researchers designed some elegant studies of positive transfer involving analogies (Gick & Holyoak, 1980, 1983). To appreciate their results, you need to become familiar with a problem first used by Duncker (1945), often called the "radiation problem." This problem is described in *Investigating Cognitive Psychology: Problems Involving Transfer*.

The correspondence between the radiation and military problems is actually quite close, although not perfect (see Table 11.2 ■). The question is whether producing a group-convergence solution to the military problem helped participants in solving the radiation problem. Consider participants who received the military problem with the convergence solution and then were given a hint to apply it in some way to the radiation problem. About 75% of the participants reached the correct solution to the radiation problem. This figure compared with less than 10% of the participants who

Table 11.2 Correspondence between the Radiation and the Military Problems

What are the commonalities between the two problems, and what is an elemental strategy that can be derived by comparing the two problems? (After Gick & Holyoak, 1983.)

	Radiation Problem	Military Problem	Radiation and Military Problems: Common Elements
Goal	Use rays to destroy tumor	Use army to capture fortress	Use force to overcome central target
Resources	Sufficiently powerful rays	Sufficiently large army	Sufficiently great force
Constraint	Unable to administer high-intensity rays from one direction only	Unable to send entire army along one road	Unable to apply full force along one path alone
Solution Plan	Administer low-intensity rays from multiple directions simultaneously	Send small groups along multiple roads simultaneously	Apply weak forces along multiple paths simultaneously
Outcome	Tumor destroyed by rays	Fortress captured by army	Central target overcome by force

Source: M. L. Gick and K. J. Holyoak (1983), "Schema Induction and Analogical Transfer," *Cognitive Psychology*, Vol. 15, pp. 1–38.

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did not receive the military story first but instead received no prior story or only an irrelevant one.

In another experiment, participants were not given the convergence solution to the military problem. They had to figure it out for themselves. About 50% of the participants generated the convergence solution to the military problem. Of these, 41% went on to generate a parallel solution to the radiation problem. That is, positive transfer was *weaker* when participants produced the original solution themselves than when the solution to the first problem was given to them (41%, as compared with 75%).

The investigators found that the usefulness of the military problem as an analog to the radiation problem depended on the induced mental set with which the problem solver approached the problems. Consider what happened when participants were asked to memorize the military story under the guise that it was a story-recall experiment and then they were given the radiation problem to solve.

Only 30% of participants produced the convergence solution to the radiation problem. The investigators also found that positive transfer improved if two, rather than just one, analogous problems were given in advance of the radiation problem.

Researchers have expanded these findings to encompass problems other than the radiation problem. They found that when the domains or the contexts for the two problems were more similar, participants were more likely to see and apply the analogy (see Holyoak, 1990). Similar patterns of data were found with various types of problems involving electricity and mathematical insight (Davidson & Sternberg, 1984; Gentner & Gentner, 1983; Novick & Holyoak, 1991).

Perhaps the most crucial aspect of these studies is that people have trouble noticing analogies unless they explicitly are told to look for them. Consider studies involving physics problems. Positive transfer from solved examples to unsolved problems was more likely among students who specifically tried to understand *why* particular examples were solved as they were, as compared with students who sought only to understand *how* particular problems were solved as they were (Chi et al., 1989). On the basis of these findings, we generally need to be looking for analogies to find them. We often will not find them unless we explicitly seek them.

People sometimes do not recognize the surface similarities of problems (Bassok, 2003). Other times they are fooled by surface similarities into believing two different kinds of problems are the same (Bassok, Wu, & Olseth, 1995; Gentner, 2000). Sometimes even experienced problem solvers are led astray. They believe that similar surface structures indicate comparable deep structures. For example, problem solvers may use the verbal content rather than the mathematical operations required in a mathematical problem to classify the problem as being of a certain kind (Blessing & Ross, 1996).

Intentional Transfer: Searching for Analogies

To find analogies between two problems, one must perceive the relationships between them (Gentner, 1983, 2000). The actual content attributes of the problems are irrelevant. In other words, what matters in analogies is not the similarity of the content but how closely their structural systems of relationships match. Because we are accustomed to considering the importance of the content, we find it difficult to push the content to the background. It also is difficult to bring form (structural relationships) to the foreground. For example, the differing content makes the analogy between the military problem and the radiation problem hard to recognize and impedes positive transfer from one problem to the other.

Children acquire the skills to do spontaneous analogical transfer around the age of 5½ years. One study presented young children with two stories about a problem; the way to solve the problems in both stories was analogous. Children under the age of 5½ were not able to solve the problem in the second story unless they were explicitly asked to compare both stories; older children could solve the problem without being asked to do a comparison between the two stories (Kikuchi, 2014). Interestingly, a study in which participants tackled problems that could be solved either in analogy to a previous problem or in a different way found that sad people tended to solve problems in an analogical way, whereas happy people tended to solve problems in nonanalogous ways (Jurásová, Biela, & Špajdel, 2014).

The opposite phenomenon is **transparency**, in which people see analogies where they do not exist because of similarity of content. In making analogies, we need to be sure we are focusing on the relationships between the two terms being compared, not just their surface content attributes. For example, in studying for final exams in two psychology courses, you may need different strategies when studying for a closed-book essay exam than for an open-book, multiple-choice exam. Transparency of content may lead to negative transfer between nonisomorphic problems if care is not taken to avoid such transfer.

Incubation

For solving many problems, the chief obstacle is not the need to find a suitable strategy for positive transfer. Rather, it is to avoid obstacles resulting from negative transfer. **Incubation**—putting the problem aside for a while without consciously thinking about it—offers one way in which to minimize negative transfer. It involves taking a pause from the stages of problem solving. For example, suppose you find that you are unable to solve a problem. None of the strategies you can think of seems to work. Try setting the problem aside for a while to let it incubate. During incubation, you must not consciously think about the problem. You do, however, allow for the possibility that the problem will be processed subconsciously. Some investigators of problem solving have even asserted that incubation is an essential stage of the problem-solving process (e.g., Cattell, 1971; von Helmholtz, 1896). Others have failed to find experimental support for the phenomenon of incubation (e.g., Baron, 1988).

A recent meta-analysis (Sio & Ormerod, 2009) of incubation research studies yielded complex findings. When people have more time to prepare to solve a problem, incubation periods are usually more fruitful. Likewise, being occupied with tasks that are highly cognitively demanding is detrimental to the effect of an incubation period. The effect of incubation furthermore depends on the kind of task, with performance on divergent-thinking tasks (in which something has to be produced) benefiting more than performance on linguistic tasks, for example. Incubation seems to help because people continue to process, below consciousness, information about a problem on which they are incubating at the same time that they are attending to other matters. Many times, when problem solvers have come to a point at which they cannot think of a strategy to solve a problem, they suffer from mental fixation. Incubation can help relieve the fixation and therefore foster the problem-solving process (Koppel & Storm, 2014).

Embodied Cognition and Problem Solving

Cognitive psychologists are interested not only in pure cognitive processes but also in how humans use their body to aid in cognitive processes. Obviously, our bodies and minds are connected in many different ways, and the feedback we get from our bodies or the actions we do with our bodies actually can influence our thought processes. **Embodied cognition** is the theory that the mind influences the body and the body influences the mind. According to theories of embodied cognition, our bodies'

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interactions with the physical world influence our cognitive processes (Barsalou, 2008; Thomas & Lleras, 2009).

Remember the string problem we discussed earlier in this chapter? How do you think physical processes can help participants solve this problem? One study (Thomas & Lleras, 2009) had subjects work on the two-string problem. Subjects were asked, whenever an alarm tone rang, to perform physical movements. Some subjects were asked to swing their arms back and forth, whereas other subjects were asked to stretch their arms out to both sides. After 16 minutes, 85% of the swing group participants had solved the problem, whereas only 62% of the stretch group had found a solution to the problem. None of the participants had perceived a connection between their physical exercises and the insight problem they were working on, but apparently the physical movements had an impact on their problem solving.

In a study on embodied cognition, participants worked on problems in a variety of conditions, for example, sitting inside or outside of an actual cardboard box or walking around freely as opposed to along a fixed line along the floor (Leung et al., 2012). The researchers found that when we physically enact metaphors that are related to problem solving (like "putting two and two together" or "thinking outside the box"), our ability to solve the problems is enhanced.

To take advantage of physical motions to solve problems, it is likely important, however, that we have enough spatial working-memory capacity at our disposal. One study had participants work on the radiation problem (presented earlier in this chapter) and found that participants who made eye movements that embodied the solution of the problem were more successful than participants who made unrelated eye movements. Performing related eye movements did not help, however, if participants' spatial working memory was overloaded (Thomas, 2013).

Neuroscience and Planning during Problem Solving

One way to invest enough initial time in a problem is by forming a plan of action for the problem. As previously discussed, planning saves time and improves performance. In one study employing variants of the Tower of Hanoi, when participants became more familiar with this type of problem, they showed increased planning times, which resulted in a decrease in the total number of moves (Gunzelmann & Anderson, 2003). These results highlight the importance of planning for efficient problem solving.

Recall from Chapter 2 that the frontal lobes are involved in high-level cognitive processes. It is therefore not surprising that the frontal lobes and in particular the prefrontal cortex are essential for planning for complex problem-solving tasks (Unterrainer & Owen, 2006). A number of studies using a variety of neuropsychological methods, including fMRI and positron emission tomography (PET), have highlighted activation in this region of the brain during problem solving (Unterrainer & Owen, 2006). Additionally, both the left and right prefrontal areas are active during the planning stage of complex problem solving (Newman et al., 2003). When a participant gives an incorrect response in a problem-solving task and therefore has to continue working on the problem, he or she reveals greater bilateral prefrontal activation than is associated with a correct response (Unterrainer et al., 2004). This finding would suggest that if the initial plan fails, problem solvers must devise a new plan, thereby activating the prefrontal cortex.

Further evidence for the importance of the prefrontal regions in problem solving can be seen in cases of traumatic brain injury. Both problem solving and planning ability decline following traumatic brain injury (Catroppa & Anderson, 2006). In fact, with regard to the problem-solving ability of patients with traumatic brain injury, those patients who performed best were ones with limited damage to the left prefrontal regions (Cazalis et al., 2006).

In the Tower of London task, other areas, including the premotor cortex and the parietal regions, also were activated (Newman et al., 2003; Unterrainer & Owen, 2006). This additional activation is likely the result of the need for attention and planning for movement. In addition to the prefrontal regions, the same areas active during use of visual spatial working memory also are active during the solution of the Tower of London task (Baker et al., 1996).

Researchers have studied information processing of people engaged in complex problem-solving situations, such as playing chess and performing logical derivations (Bilalic et al., 2008a; Kiesel et al., 2009; Simon, 1976). For example, a simple, brief task might require the participants first to view an arithmetic or geometric series. Then they must figure out the rule underlying the progression. And finally they must guess what numeral or geometric figure might come next. More complex tasks might include some of the tasks mentioned before, like the water-jar problem.

CONCEPT CHECK

1. How can mental sets impair our problem-solving ability?
2. What is negative transfer?
3. Are analogies always useful for problem solving?
4. What is the role of incubation in problem solving?

Expertise: Knowledge and Problem Solving

Even people who do not have expertise in cognitive psychology recognize that knowledge, particularly expert knowledge, greatly enhances problem solving. **Expertise** is superior skills or achievement reflecting a well-developed and well-organized knowledge base. What interests cognitive psychologists is the reason that expertise enhances problem solving. Why can experts solve problems in their field more successfully than can novices? Do experts know more problem-solving algorithms, heuristics, and other strategies? Do experts know better strategies? Or do they just use these strategies more often? What do experts know that makes the problem-solving process more effective for them than for novices in a field? Is it all talent or just acquired skill?

Organization of Knowledge

Do you think one can distinguish beers by their flavor? In one study, beer experts and beer novices experienced tasting a series of beers (Valentin et al., 2007). Both groups could sort the beers equally well. The beer experts, however, performed better on subsequent recognition tasks. These findings suggest that there was no difference in perceptual abilities between the experts and the novices, but there was a difference in memory between these two groups. The researchers concluded that the beer experts had a superior framework for encoding and retrieving the new beer information.

Knowledge can interact with understanding in problem solving as well (Whitten & Graesser, 2003). Consider a study investigating how knowledge interacts with coherence of a text. Investigators presented children with biology texts (McNamara et al., 1996).

Half the children in the study had high levels of domain knowledge about biology and half had low levels. In addition, half the texts were highly coherent, meaning that they made clear how the various concepts in the text related to each other. The other half of the texts were of low coherence, meaning that they were more difficult to read because the ideas did not flow smoothly. Readers then had to do a variety of problem-solving tasks based on what they had read. As the authors predicted, participants with low domain knowledge performed better when the texts were highly coherent. This finding suggests that, in general, learners do better when they are presented with new material in a coherent way.

Surprisingly, however, the high-knowledge group performed better when the texts were of low rather than high coherence. The authors of the study suggested that high-knowledge readers may have been, essentially, on automatic pilot when reading the high-coherence texts and were not paying much attention because they thought they knew what was in the texts. The low-coherence texts forced them to pay attention. These results point out the importance of attentional processes when people solve problems. This is particularly relevant in domains in which they are expert and in which they therefore may not feel they have to pay attention.

Elaboration of Knowledge

Do you remember the study with chess experts and novices described in *Believe It or Not* at the beginning of this chapter? What differentiated the experts from the novices was the amount, organization, and use of knowledge. The chess study included two tasks: One involved a random array of pieces and the other a meaningful arrangement of pieces (Figure 11.13 ■). For both chess tasks, the experts used heuristics to store and retrieve information about the positions of the pieces on the chessboard. The novices, to the contrary, had not stored significant knowledge about positions. The key difference, therefore, was that chess experts had stored and organized in memory tens of thousands of particular board positions. When they saw sensible board positions, they could use the knowledge they had in memory to help them. They were able to remember the various board positions as integrated, organized chunks of information. As you may recall from Chapter 5, the ability to chunk information into meaningful units allows for superior memory and capacity. For random scatterings of pieces on the board, however, the knowledge of the experts was not useful. The experts had no advantage over the novices. Like the novices, they had to try to memorize the distinctive interrelations among many discrete pieces and positions. This memorization requires storing many more items, thus taxing one's memory abilities. Thus, the experts performed better at memorizing actual board positions, but they had no advantage over beginners when random board positions had to be memorized.

Retrieval processes for recognizing board arrangements are instrumental in grand master–level chess players' success when compared with novices' play (Gobet & Simon, 1996a, 1996b, 1996c). Even when grand masters are time constrained and their look-ahead processes are curtailed, their constrained performance does not differ substantially from their unconstrained playing. Thus, an organized knowledge system is relatively more important to experts' performance in chess than even the processes involved in predicting future moves.

Other studies have examined experts in other domains like radiology (Lesgold et al., 1988), physics (Larkin et al., 1980), and meditation (Brefczynski-Lewis et al., 2007). These studies revealed the same thing again and again. What differentiated experts from novices were their schemas for solving problems within their own domains of expertise (Glaser & Chi, 1988). The schemas of experts involve large, highly interconnected units of knowledge. They are organized according to underlying structural similarities among

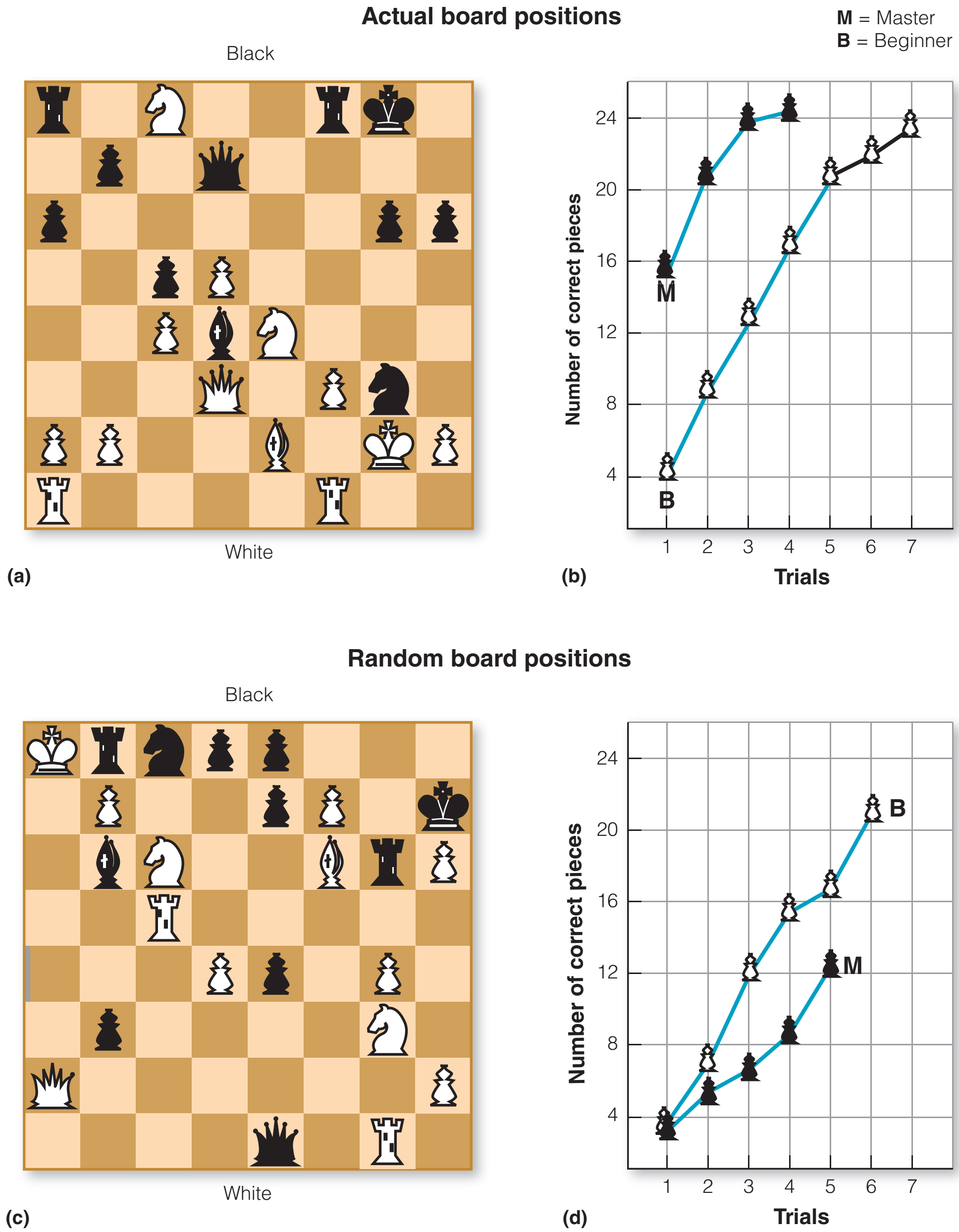

Figure 11.13 **Experts versus Novices in Playing Chess.** When experts and novices were asked to recall realistic patterns of chess pieces, as in panel (a), experts demonstrated much better performance, as shown in panel (b). However, when experts and novices were asked to recall random arrangements of chess pieces, as shown in panel (c), experts performed no better than novices, as shown in panel (d). If anything, experts were at a disadvantage.

Source: Based on http://en.chessbase.com/post/the-geometry-of-expertise

knowledge units. In contrast, the schemas of novices involve relatively small and disconnected units of knowledge. They are organized according to superficial similarities (Bryson et al., 1991).

Experts and novices also differ in how they classify various problems, describe the essential nature of problems, and determine and describe solutions (Chi, Glaser, & Rees,

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1982; Larkin et al., 1980). One study exploring problem-solving strategies in both expert and novice mathematicians noted a difference in the use of visual depictions: Novice problem solvers use a visual representation to solve problems that have an obvious spatial component, such as geometry problems, whereas expert problem solvers used visual representations to solve a wide range of mathematical problems (Stylianou & Silver, 2004) whether or not they had an obvious spatial component. The ability to apply a visual representation to a variety of problems allows greater flexibility and an increased likelihood that a solution will be found.

An interesting study looked at the role of knowledge in understanding and interpreting a news broadcast regarding a baseball game (Hambrick & Engle, 2002). A total of 181 adults with a wide range of baseball knowledge listened to radio broadcasts recorded by a professional baseball announcer. The announcements sounded like a real game. After each broadcast, memory for changes in the status of the game were measured. For example, participants would be asked questions about which bases were occupied after each player's turn at bat and about the numbers of outs and of runs scored during the inning. Baseball knowledge accounted for more than half the reliable variation in participants' performance. Working memory capacity also mattered, but not nearly so much as knowledge. Thus, people can remember things better and solve problems with what they remember better if they have a solid knowledge base with which to work.

Reflections on Problem Solving

Another difference between experts and novices can be observed by asking problem solvers to report aloud what they are thinking as they are attempting to solve various problems (Bilalic, 2008b; Dew et al., 2009). Statements made by problem solvers are called *verbal protocols*. An interesting effect of verbal protocols is that they can lead to increased problem-solving ability. In one study, when participants spoke aloud or wrote about their problem-solving strategy in a way that centered on the objects of the problem, an improvement in quality of solutions was observed (Steif et al., 2006). In another study, problem-solving ability was enhanced when participants wrote a description of their problem-solving strategy as compared with when they spoke about their strategy (Pugalee, 2004). Thus, it seems that, for novice problem solvers, communicating problem-solving strategies improves performance.

Another difference between expert and novice problem solvers is the time spent on various aspects of problems, and the relationship between problem-solving strategies and the solutions reached. Experts appear to spend proportionately more time determining how to represent a problem than do novices (Lesgold, 1988; Lesgold et al., 1988), but they spend much less time actually implementing the strategy for solution.

The differences between experts and novices in their expenditure of time can be viewed in terms of the focus and direction of their problem solving. Experts seem to spend relatively more time than novices figuring out how to match the given information in the problem with their existing schemas. In other words, experts try to compare what they know about the problem with how the information they have matches what they already know, based on their expertise. Once experts find a correct match, they quickly can retrieve and implement a problem strategy. Thus, experts seem able to work forward from the given information ("What do I know?") to find the unknown information ("What do I need to find out?"). They implement the correct sequence of steps, based on the strategies they have retrieved from their schemas in long-term memory (Chi, Glaser, & Rees, 1982).

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in the lab of **K. ANDERS ERICSSON**

Individual Differences in Problem Solving

For as long as I can remember I have been fascinated by individual differences in thinking and problem solving. In particular I wondered whether it would be possible for regular persons, like myself, to learn from experts and exceptional thinkers, such as scientists and chess masters. Would it be possible to find out how they attained their performance so that I could improve my abilities by adopting their methods of study and practice?

Courtesy of K. Anders Ericsson.

K. Anders Ericsson

Most of the descriptions of the development of exceptional individuals' thinking come from informal interviews with these experts about what happened many years or even decades ago. Scientists, however, have to be skeptical of this type of recalled information that rarely can be verified with scientific methods.

In my research lab, we have invited expert performers, such as musicians, chess players, and athletes, to reproduce their superior performance under controlled conditions, so we can compare their performance to those of less-skilled individuals on the same tasks (Ericsson, 2009; Ericsson & Williams, 2007). We instruct the experts to give verbal expression to their thoughts as they perform (i.e., "think aloud") or report their thoughts immediately after their task performance is completed (see Ericsson, 2006a, for a description of the fundamental differences between "think-aloud" and introspective analysis). On the basis of this type of verbal report, along with specially designed experiments to test the reported information, we and other colleagues have been able to uncover the complex skills and thought processes that mediate the superior performance in people with exceptional memory (for a recent study, see Hu & Ericsson, 2012). We have been particularly interested in how experts, such as chess masters, musicians, athletes, and mental calculators, have acquired memory skills to allow them to plan, monitor, and evaluate complex sequences of actions (Ericsson, 2006a; Moxley et al., 2012).

In my laboratory, we interview the experts about their current practice methods and how their performance in the domain developed—often their reported information can be verified by their parents and teachers or by public records from competitions. Perhaps the most general and intriguing finding is that experts' superior performance is closely linked to their engagement in massive amounts of teacher-designed practice activities designed to improve specific aspects of their performance. Thus, future expert performers primarily differ from their peers in their engagement in special practice activities that help them to exceed their current performance by repetition and gradual refinement through problem solving (deliberate practice; Ericsson, 2006b, 2014).

In domains such as music, sports, and chess, the best performers started early and have spent up to four hours each day for many years engaged in deliberate practice. At age 20 the top violinists had accumulated an estimated amount of deliberate practice between 3,000 and 12,000 hours (Ericsson, Krampe, & Tesch-Römer, 1993). Over a decade later Malcolm Gladwell's (2008) *Outliers: The Story of Success* proposed "the 10,000-hour rule," in which he misinterpreted our findings and stated that *all* of our top performers had engaged in *more than* 10,000 hours of practice, although less than half of our elite sample had reached 10,000 hours (the average of our top sample; Ericsson, 2013). This misinterpretation led Gladwell to propose that 10,000 hours of practice was the minimum necessary for anyone to reach an international level of performance—"the magic number for true expertise" (Gladwell, 2008, p. 40). Despite this misinterpretation, it is clear that elite performers have accumulated an amazing number of hours of practice individually supervised by teachers (deliberate practice) before they start winning at an international level (Ericsson, 2014). Detailed analysis of the expert performers' deliberate practice in sports and music has uncovered types of intense training activities that are capable of modifying physical characteristics of the body, such as increasing the degree of myelinization of nerve circuits in the brain, increasing the number of capillaries supplying blood to critical muscles, and enlarging the chambers of the heart (Ericsson, 2006b, 2013).

Research on expert performance has produced new insights into the cognitive structures and physiological adaptations that can be attained after thousands of hours of deliberate efforts to improve. The scientific study of the lives and practice methods of expert performers appears to be a promising area for increasing our knowledge about what is humanly possible when individuals are motivated to reach their highest levels of achievement.

Consider the ways an expert doctor and a novice medical student might handle a patient with a set of symptoms. The novice is not sure what to make of the symptoms. He somewhat haphazardly orders a long and expensive series of medical tests. He is hoping that with a nearly complete set of symptomatic information, he may be able to make a correct diagnosis. The more experienced doctor, however, is more likely to immediately recognize the symptoms as fitting into a diagnostic pattern or one of a small number of patterns. This doctor orders only a small number of highly targeted tests. She is able to choose the correct diagnosis from among the limited number of possibilities. She then moves on to treat the diagnosed illness.

Novices, in contrast, seem to spend relatively little time trying to represent the problem. Instead, they choose to work backward from the unknown information to the given information. That is, they go from asking what they need to find out to asking what information is offered and what strategies do they know that can help them find the missing information. Often, novices use means–ends analysis (see Hunt, 1994). Thus, novices often consider more possible strategies than experts consider (see Holyoak, 1990). For experts, means–ends analysis of problems serves only as a backup strategy. They turn to it only if they are unable to retrieve an appropriate strategy, based on their existing schemas. Experts are more likely to use the strategy of working forward.

Thus, experts have not only more knowledge but also better-organized knowledge. They use their knowledge more effectively. Furthermore, the schemas of experts involve not only greater declarative knowledge about a problem domain but also more procedural knowledge about strategies relevant to that domain. Perhaps because of their better grasp of the strategies required, experts more accurately predict the difficulty of solving problems than do novices. Experts also monitor their problem-solving strategies more carefully than do novices (Schoenfeld, 1981).

Automatic Expert Processes

Through practice in applying strategies, experts may automatize various operations. They can retrieve and execute these operations easily while working forward (see VanLehn, 1989). They use two important processes: One is *schematization,* which involves developing rich, highly organized schemas; the other is *automatization,* which involves consolidating sequences of steps into unified routines that require little or no conscious control. Through these two processes, experts may shift the burden of solving problems from limited-capacity working memory to infinite-capacity long-term memory. They thereby become increasingly efficient and accurate in solving problems. The freeing of their working-memory capacity may better enable them to monitor their progress and their accuracy during problem solving. Novices, in contrast, must use their working memory to hold multiple features of a problem and various possible alternative strategies. This effort may leave novices with less working memory available for monitoring their accuracy and their progress toward solving the problem.

Automaticity can be seen in mathematics, for example, when low-level skills, such as counting and adding, become automatic (Tronsky, 2005). These skills reduce the working-memory load and allow for higher level mathematical procedures to be complete.

The automaticity of experts, however, actually may hinder problem solving by making them less flexible. This can occur when experts are tackling problems that differ structurally from the problems they normally encounter (Frensch & Sternberg, 1989). Initially, novices may perform better than experts when the problems appear structurally different from the norm. Eventually, however, the performance of experts generally catches up to and surpasses that of novices (Frensch & Sternberg, 1989; Lesgold, 1988). Perhaps this difference results from the experts' richly developed schemas and their enhanced self-monitoring skills. The highest level experts, however, are less vulnerable

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to falling prey to their own expertise (Bilalic et al., 2008b). They have the wisdom to realize their own susceptibility to becoming entrenched and take this susceptibility into account.

Not even the performance of experts is always fully automated. Experts, just like everyone else, are constantly learning and thus need to exert some amount of conscious cognitive control over their behavior (Ericsson, 2014). Table 11.3 ■ summarizes the various characteristics of expert problem solving.

Table 11.3 What Characterizes Expertise?

	Experts	Novices
Schemas	• Have large, rich schemas with a great deal of declarative knowledge about domain • Schemas contain a great deal of procedural knowledge about problem-solving strategies relevant to a given domain	• Have relatively impoverished schemas with relatively less declarative knowledge about domain • Schemas contain relatively little procedural knowledge about problem strategies relevant to the given domain
Organization	Have well-organized, highly interconnected units of knowledge in schemas	Have poorly organized, loosely interconnected, scattered units of knowledge
Use of time	Spend more time determining how to represent a problem	Spend more time searching for and executing a problem strategy
Representation of problems	Develop sophisticated representations of problems based on structural similarities among problems	Develop relatively poor and naive representations of problems based on superficial similarities among problems
Work direction	Work forward from given information to implement strategies for finding unknown information	Work backward from focusing on the unknown to finding problem strategies that make use of given information
Strategy	Use strategy based on elaborate schema of problem strategies; means–end analysis is only used for unusual, atypical problems	Use means–ends analysis as a strategy for handling most problems
Automatization	Automatized many sequences of steps within problem strategies	Show little or no automatization of any sequences of steps within problem strategies
Efficiency	Show highly efficient problem solving; when time constraints are imposed, solve problems more quickly than novices	Show relatively inefficient problem solving; solve problems less quickly
Prediction of difficulty	Accurately predict the difficulty of solving particular problems	Inaccurately predict the difficulty of solving particular problems
Monitoring	Carefully monitor own problem-solving strategies and processes	Show poor monitoring of own problem-solving strategies and processes
Accuracy of solution	Show high accuracy in reaching appropriate solutions	Show much less accuracy in reaching appropriate solutions
Confronting unusual problems	Take relatively more time than novices both to represent the problem and to retrieve appropriate problem strategies	Take relatively less time both to represent the problem and to retrieve problem strategies
Handling contradictory information	Show flexibility in adapting to a more appropriate strategy	Show less ability to adapt to new information that contradicts initial problem representation and strategy

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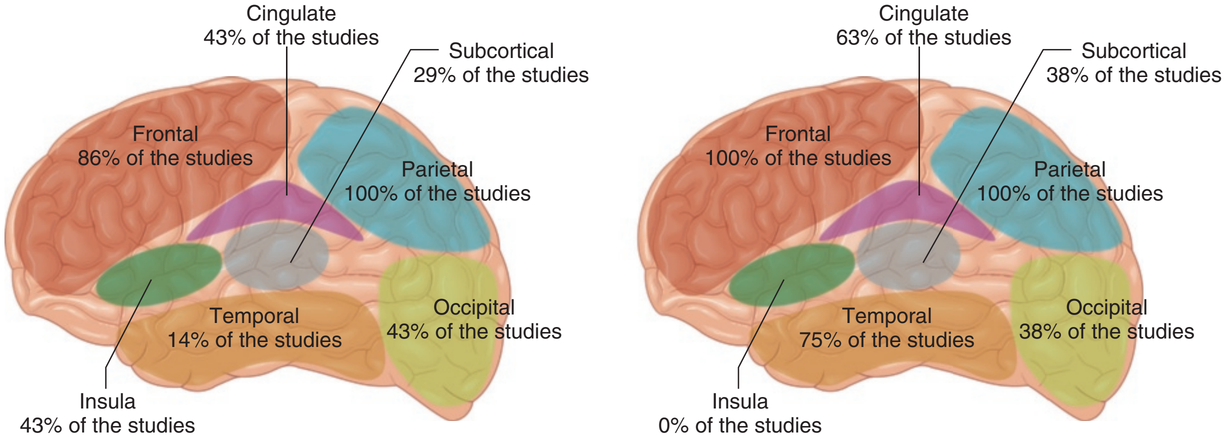
Long-Term Working Memory and Expertise

An expert frequently has to hold large amounts of information in memory to perform a tasks For example, chess masters can play chess games without seeing the chess board, which means they can hold the positions of all the chess pieces in memory. People who perform calculations like the multiplication of two six-digit numbers in their mind must be able to hold intermediate results in their memory. It is not possible for working memory to hold such large amounts of information. How do experts perform these tasks then?

To answer this question, it has been suggested that experts develop a long-term working memory in their area of expertise (Ericsson & Kintsh, 1995). The concept of long-term working memory has been developed because to execute their skills experts often have to hold more information in their working memory than working memory possibly can hold. Long-term working memory retains memories in a stable form (unlike short-term working memory) but can be accessed only with adequate retrieval cues. When the expert performs and gets interrupted, he will be able to retrieve the information stored in long-term working memory again, using the retrieval cues.

Neuroimaging research backs up the notion of long-term working memory in the performance of experts. Guida et al. (2012) reviewed a number of neuroimaging studies and suggested a two-stage framework for how expertise is acquired. When novices perform a task, their working memory is highly activated, as seen in prefrontal and parietal activation. The experts' long-term memory (represented by temporal activation), in contrast, is not much involved. As novices gain more experience, they start chunking information in their working memory, which leads to a decrease in activation in working memory (prefrontal–parietal activation). You can see in Figure 11.14(a) ■ that a large number of studies found a decrease in activation in frontal and parietal areas as novices increasingly practiced a task. When the novices accrue even more experience, those chunks start stabilizing in long-term memory. At this point, one can begin to see the involvement of long-term memory (temporal) areas in addition to working memory when a task is performed.

Figure 11.14(b) ■ shows that a large percentage of studies found the involvement of temporal areas when experts performed a task. Thus, one significant difference between


Cingulate
43% of the studies
Subcortical
29% of the studies
Frontal
86% of the studies
Parietal
100% of the studies
Temporal
14% of the studies
Occipital
43% of the studies
Insula
43% of the studies
Cingulate
63% of the studies
Subcortical
38% of the studies
Frontal
100% of the studies
Parietal
100% of the studies
Temporal
75% of the studies
Occipital
38% of the studies
Insula
0% of the studies

(a) Brains of Novices **(b) Brains of Experts**

■ **Figure 11.14 Brain Activation and Working Memory.** (a) As novices practice a task and begin chunking larger pieces of information together in their working memory, activation in prefrontal and parietal areas decreases. You can see that many of the studies included in the meta-analysis found this decrease in activation.

(b) A large number (75%) of studies found when experts work on a task their long-term memory (temporal areas of their brain) is involved.

experts and novices is the involvement of long-term memory as the experts perform a task. It has been estimated that it takes around six years before such a functional brain reorganization can be observed (Chen et al., 2006; Pesenti et al., 2001).

Innate Talent and Acquired Skill

A richly elaborated knowledge base is crucial to expertise in a specific area or domain, but not all differences in performance can be explained in terms of knowledge level alone. There is considerable debate as to whether differences between novices and experts and among different experts themselves are due either to innate talent or to the quantity and quality of practice in a domain. Many espouse the "practice makes perfect" point of view (e.g., see Ericsson, 2003). The practice should be deliberate, or focused. It should emphasize acquisition of new skills and applications rather than mindless repetition of what the developing expert already knows how to do. Ericsson (2014) argues that when people invest thousands of hours into acquiring a skill, their skills actually may change so that novice or intermediate performers cannot even be validly compared with experts.

Some, however, take an alternative approach. This approach acknowledges the importance of practice in building a knowledge and skill base. It also underscores the importance of something like talent. Studies have shown that factors, like starting age, personality traits like "grit" (persistence when trying to accomplish goals), passion, and general intelligence may play a role in the acquisition of expert skills (for a review, see Hambrick et al., 2014).

Indeed, the interaction between innate abilities modified by experience is widely accepted in the domain of language acquisition as well as in other domains. Certainly, some skill domains are heavily dependent on nurture. For example, wisdom is partly knowledge based. The knowledge one uses to make wise judgments is necessarily a result of experience (Baltes & Smith, 1990).

Experts in some domains perform at superior levels by virtue of prediction skills. For example, expert typists move their fingers toward keys corresponding to the letters they will need to type more quickly than do novice typists (Norman & Rumelhart, 1983). Indeed, the single best predictor of typing speed is how far ahead in the text a typist looks when typing (Ericsson, 2003). The farther ahead he or she looks, the better the typist is able to have fingers in position as needed. When typists are not allowed to look ahead in their typing, the advantage of expert typists is largely eliminated (Salthouse, 1984). Experts in sign language show variations in sign production in preparation for the next sign (Yang & Sarkar, 2006). Rather than produce one sign in isolation, these signers are looking ahead. Looking ahead allows experts to produce signs more quickly than do novices. Expert musicians, too, are better able to sight-read than novices by virtue of their looking farther ahead in the music so they can anticipate what notes will be coming up (Sloboda, 1984). Even in sports, such as tennis, experts are superior to novices in part by virtue of their being able to predict the trajectory of an approaching ball more rapidly and accurately than novices (Abernethy, 1991).

Another characteristic of experts is that they tend to use a more systematic approach to difficult problems within their domain of expertise than do novices. For example, one study compared strategies used by problem solvers in a simulated biology laboratory (Vollmeyer, Burns, & Holyoak, 1996). The investigators found that better problem solvers were more systematic in their approach to the lab than were poorer problem solvers. For example, in seeking an explanation of a biological phenomenon, they were more likely to hold one variable constant while changing other variables.

Many scientists in the field of expertise prefer to minimize the contributions of talent to expertise by locking talent in the trunk of "folk" psychology (but see Sternberg, 1996a).

This tendency is not surprising, given two factors. The first is the widespread use of the term *talent* outside the scientific community. The second is the lack of an adequate, testable definition of talent.

Genetic heritage seems to make some difference in the acquisition of at least some kinds of expertise. Studies of the heritability of reading disabilities, for example, seem to point to a strong role for genetic factors in people with a reading disability (see Haworth et al., 2009; Platko et al., 2008). Furthermore, differences in the phonological awareness required for reading ability could be a factor in reading for which individual differences are at least partially genetic (Wagner & Stanovich, 1996). In general, even if the role of practice is found to account for much of the expertise shown in a given domain, the contributions of genetic factors to the remaining portion of expertise could make some difference in a world of intense competition.

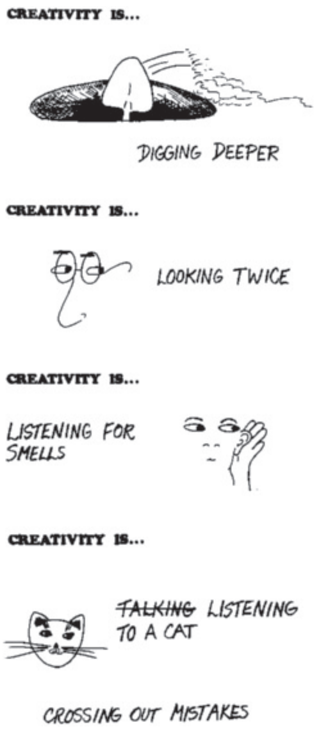
CONCEPT CHECK

1. How do the schemas of experts and novices differ?
2. Why does automatization help experts solve problems efficiently?
3. How does talent contribute to expertise?

Creativity

How can we possibly define creativity as a single construct that unifies the work of Leonardo da Vinci and Marie Curie, of Vincent Van Gogh and Isaac Newton, and of Toni Morrison and Albert Einstein? There may be about as many narrow definitions of creativity as there are people who think about creativity (Figure 11.15 ■). However, most investigators in the field of creativity would broadly define **creativity** as the process of producing something that is both original and worthwhile (Csikszentmihalyi, 1999, 2000, 2013; Kozbelt, Beghetto, & Runco, 2010; Lubart & Mouchiroud, 2003; Sternberg, 2012; Sternberg & Lubart, 1996). The *something* could take many forms. It might be a theory, a dance, a chemical, a process or procedure, a story, a symphony, or almost anything else.

What does it take to create something original and worthwhile? What are creative people like? Almost everyone would agree that creative individuals show creative productivity. They produce inventions, insightful discoveries, artistic works, revolutionary paradigms, or other products that are both original and worthwhile. Conventional wisdom suggests that highly creative individuals also have creative lifestyles (Robinson, 2011). These lifestyles are characterized by flexibility, nonstereotyped behaviors, and nonconforming attitudes (Sawyer, 2013).



■ **Figure 11.15 What Is Creativity?** Here are some original and worthwhile ways of defining creativity. How do you define creativity?

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Characteristics of Creative People

Some psychologists measure creativity through *divergent production*—the generation of a diverse assortment of appropriate responses, an approach originated by Guilford (1950; see also Runco & Albert, 2010, for a history of the field, and Plucker & Makel, 2010, for a discussion of assessment of creativity). For example, creative individuals often have high scores on assessments of creativity. An example of such an assessment is found in the Torrance Tests of Creative Thinking (Torrance, 1974, 1984). They measure the diversity, quantity, and appropriateness of responses to open-ended questions. An example of such a question is to think of all the possible ways in which to use a paper clip or a ballpoint pen. Torrance's test also assesses creative figural responses. For example, a person might be given a sheet of paper displaying some circles, squiggles, or lines. The test would assess how many different ways the person had used the given shapes to complete a drawing. It would consider particularly how much the person had used unusual or richly elaborated details in completing a figure.

Other psychological researchers have focused on creativity as a cognitive process by studying problem solving and insight (Finke, 1995; Klein, 2013; Ward & Kolomyts, 2010; Weisberg, 1988, 2009). Some of these researchers believe that what distinguishes remarkably creative individuals from less remarkable people is their expertise and commitment to their creative endeavor. Highly creative individuals work long and hard. They study the work of their predecessors and their contemporaries. They thereby become thoroughly expert in their fields. They then build on and diverge from what they know to create innovative approaches and products (Weisberg, 1988, 2009) and thereby change society (Moran, 2010). One study examined the creativity of projects completed by design students. The researchers found that the greater the knowledge amassed by a student, the greater, on average, the creativity of the project (Christiaans & Venselaar, 2007).

Some computer programs, such as those composing music or rediscovering scientific principles, can be viewed as creative. The question one always needs to ask with these programs is whether their accomplishments truly are comparable to those of creative humans, and whether the processes they use to be creative are the same as those used by humans (Boden, 1999). Langley et al.'s (1987) programs of scientific discovery actually *re*discover scientific ideas rather than discover them for the first time. Even Deep Blue, the computer program that beat world-champion chess player Gary Kasparov, did so not by playing chess more creatively than Kasparov. Rather, it won through its enormous powers of rapid computation.

AP Images/Karl-Heinz Kreifelts

Even before Judit Polgar was born, her parents decided she was going to be a chess champion. Accordingly, she received early and intensive training in chess. She has won two Olympic gold medals in chess and in 2011 became number one on the women's world ranking list for the 50th time. In 2014, she announced her retirement from competitive chess.

Personality and motivation play important roles in creativity (Barron, 1988; Feist, 2010; Hennessey, 2010; Runco, 2010). Often underlying creativity are flexible beliefs and broadly accepting attitudes toward other cultures, other races, and other religious creeds. Some investigators have focused on the importance of motivation in creative productivity (e.g., Amabile, 1996; Collins & Amabile, 1999).

One may differentiate intrinsic motivation, which is internal to the individual, from extrinsic motivation, which is external to the individual. For example, intrinsic motivators might include sheer enjoyment of the creative process or personal desire to solve a problem. Intrinsic motivation is essential to creativity. Extrinsic motivators might include a desire for fame or fortune. Extrinsic motivators actually may impede creativity under many but not all circumstances (Amabile, 1996; Prabhu, Sutton, & Sauser, 2008). Curiously, in one

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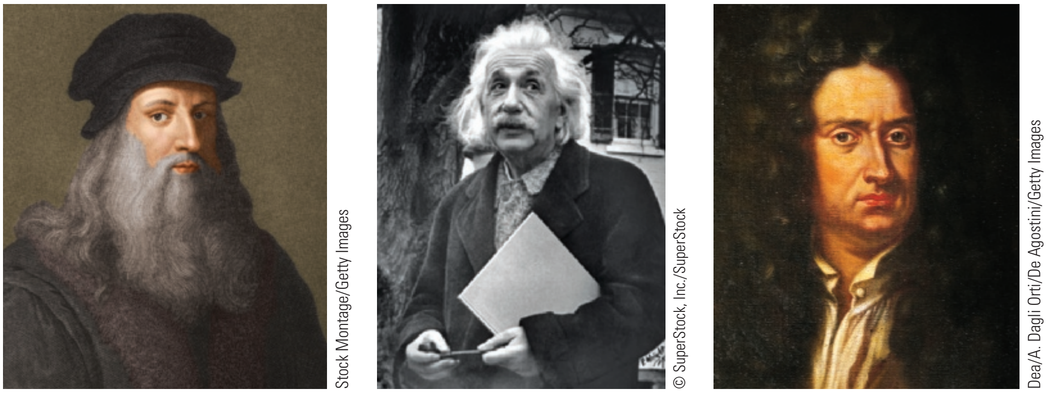

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What do creative people such as Leonardo da Vinci, Albert Einstein, and Isaac Newton have in common?

experiment, extrinsic rewards for novel performance led to an increase in both creativity and intrinsic motivation. Conversely, extrinsic rewards for normal performance resulted in a decrease in both creativity and intrinsic motivation (Eisenberger & Shanock, 2003).

Certain traits seem consistently to be associated with creative individuals (Feist, 1998, 1999; Prabhu et al., 2008; Zhang & Sternberg, 2009; Zhang, Sternberg, & Rayner, 2012). In particular, creative individuals tend to be more open to new experiences, self-confident, self-accepting, impulsive, ambitious, driven, dominant, and hostile than less creative individuals. They also are less conventional.

Creativity needs to be viewed in the contexts in which it occurs (Csikszentmihalyi, 1988, 1996, 2013; Moran, 2010). One can seek to understand creativity by going beyond the immediate social, intellectual, and cultural context to embrace the entire sweep of history (Simonton, 1994, 1997, 1999, 2010a, 2014). Creative contributions, almost by definition, are unpredictable because they violate the norms established by the forerunners and the contemporaries of the creator. Among the many attributes of creative individuals are the abilities to make serendipitous discoveries and to pursue such discoveries actively (Simonton, 1994).

Evolutionary thinking also can be used to study creativity (Cziko, 1998; Gabora & Kaufman, 2010; Runco, 2014; Simonton, 2010a). Underlying such models is the notion that creative ideas evolve much as organisms do. The idea is that creativity occurs as an outcome of a process of blind variation and selective retention (Campbell, 1960). In blind variation, creators first generate an idea. They have no real sense of whether the idea will be successful (selected for) in the world of ideas. As a result, their best bet for producing lasting ideas is to go for a large quantity of ideas. Some of these ideas then will be valued by their field. That is, they will be selectively retained by virtue of their being labeled as creative.

Creative individuals tended to have moderately supportive but often strict and relatively chilly (i.e., not warmly affectionate and nurturing) early family lives. They have highly supportive mentors. Most showed an early interest in their chosen field, but many were not particularly noteworthy (Gardner, 1993a, Policastro & Gardner, 1999; see also Gruber, 1974/1981; Gruber & Davis, 1988; Simonton, 2010a). They generally tended to show an early interest in exploring uncharted territory; but only after gaining mastery of their chosen field, after about a decade of practicing their craft, did they have their initial revolutionary breakthrough. Most creators seemed to have obtained at least some emotional and intellectual support at the time of their breakthrough. However, following this initial breakthrough (and sometimes before), highly creative individuals generally dedicated all their energies to their work. They

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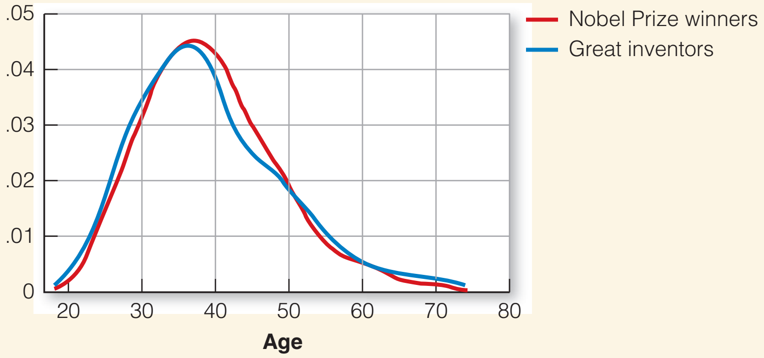
BELIEVE IT OR NOT

When Will You Do Your Best Work?

Creative people often yearn to make a contribution that will change the world. What they may not realize is that the age at which they make such a contribution depends not only on them but also on the field that they choose to enter (see Figure 11.16 ■). Dean Simonton (1988, 1991, 1994; see also contributions in Simonton, 2014) has studied career trajectories for creative contributions. He has found that the age at which people make their outstanding creative contributions varies somewhat widely by field. For example, in chemistry, the average age of one's greatest work is 38 years. In medicine, it is 42 years. Among composers, it is around 41 years. But notice this: Despite the variation, chances are pretty good that, on average, the best work will occur roughly around the age of 40 years. So if you view yourself as creative but have not yet had your great idea, and you are under 40 years old, remember that the best is probably yet to come. And remember that creative contributions can be made even late in career (Sternberg & Kaufman, 2012).



■ **Figure 11.16** The ages at which individuals produced Nobel Prize–winning insights and great technological contributions over the 20th century.

sometimes abandoned, neglected, or exploited close relationships during adulthood. About a decade after their initial creative achievement, most of the creators Gardner studied made a second breakthrough. It was more comprehensive and more integrative but less revolutionary. Whether a creator continued to make significant contributions depended on the particular field of endeavor. Poets and scientists were less likely to do so than musicians and painters.

An alternative integrative theory of creativity suggests that multiple individual and environmental factors must converge for creativity to occur (Sternberg, 2012; Sternberg & Lubart, 1991, 1996). What distinguishes the highly creative individual from the only modestly creative one is the confluence of multiple factors, rather than extremely high levels of any particular factor or even the possession of a distinctive trait. This theory is termed the *investment theory of creativity.* The theme unifying these various factors is that the creative individual takes a buy-low, sell-high approach to ideas (Sternberg & Lubart, 1995, 1996). In buying low, the creator initially sees the hidden potential of ideas that are presumed by others to have little value. The creative person then focuses attention on this idea. It is, at the time of the creator's interest, unrecognized or undervalued by contemporaries, but it has great potential for creative development. The creator then develops the idea into a meaningful, significant creative contribution until at last others also can recognize the merits of the idea. Some of these contributions may be stunning; others more modest (Sternberg, Kaufman, & Pretz, 2001, 2002). Once the idea has been developed and its value is recognized, the creator then sells high. He or she then moves on to other pursuits and looks for the hidden potential in other undervalued ideas. Thus, the creative person influences the field most by always staying a step ahead of the rest. In the ideal, students would develop not only a strong knowledge base, but also the skills and attributes discussed here that are essential to creativity (Beghetto, 2010; Smith & Smith, 2010).

People may have the potential to be creative but then find that their tendency toward dogmatism interferes with their creativity production: They just don't want to see things in new ways (Ambrose & Sternberg, 2012)—perhaps worse are the people who are creative but who use their creativity for destructive ends (Cropley et al., 2010).

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Creativity in Problem Solving

Line up six toothpicks. Ask a friend to make four equilateral triangles with these six toothpicks without breaking the toothpicks into pieces. Most people will not be able to do this task because they will try to make the four triangles on a single plane. When they give up, make a single triangle flat on the table with three of the toothpicks; then with the other three toothpicks, make a pyramid by joining the three toothpicks at the top and having the sides connect with the intersections of the three toothpicks on the table. Your friend was fixated on the plane of the alignment of the toothpicks. See if any of your friends can figure out this problem if you give them the toothpicks standing up in a toothpick holder.

Neuroscience and Creativity

The examination of creative thought and production has led researchers to identify brain regions that are active during creativity (Jung et al., 2013; Kaufman et al., 2010). The prefrontal regions are especially active during the creative process, regardless of whether the creative thought is effortful or spontaneous (Dietrich, 2004).

In addition to the prefrontal area, other regions have been identified as important for creativity. In one study, participants were given a list of words that were either semantically related or unrelated (Bechtereva et al., 2004). The participants were then asked to make up a story using all of these words. Forming a story from a list of unrelated words should require more creativity than using a list of semantically related words. These researchers noted that Brodmann's area (BA) 39 was active during the unrelated-list story production but not during production of stories with the list of related words. Previous research has indicated that this and related Brodmann's areas are involved in verbal working memory, task switching, and imagination (Blackwood et al., 2000; Collette et al., 2001; Sohn et al., 2000; Zurowski et al., 2002).

A selective thinning of cortical areas seems to correlate with intelligence and creativity. In particular, a thinning of the left frontal lobe, lingual, cuneus, angular, inferior parietal, and fusiform gyri is connected with high scores on creativity measures. These areas include several Brodmann's areas, including BA 39. Additionally, a relative thickness of the right posterior cingulate gyrus and right angular gyrus was related to higher creativity as well. These variations in cortical thickness, and especially a thinning in various areas, probably influence information flow within the brain (Jung et al., 2010).

CONCEPT CHECK

1. Name some of the ways to identify a creative individual.
2. What makes a contribution creative?
3. Which brain regions contribute to creative processes?

Key Themes

This chapter highlights several of the themes first presented in Chapter 1.

Domain generality versus domain specificity. Early work on problem solving, such as that by Allen Newell and Herbert Simon and their colleagues, emphasized the domain generality of problem solving. These investigators sought to write computer routines, such as the general problem solver, that would solve a broad array of problems. Later theorists have emphasized domain specificity in problem solving. They especially have called attention to the need for a broad knowledge base to solve problems successfully.

Validity of causal inference versus ecological validity. Most studies of creativity have occurred in laboratory settings. For example, Paul Torrance gave students paper-and-pencil tests of creative thinking administered in classrooms. In contrast, Howard Gruber has been interested only in creativity as it occurred in natural settings, such as when Darwin generated his many ideas behind the theory of evolution.

Applied versus basic research. The field of creativity has generated many insights regarding fundamental processes used in creative thought. But the field has also spawned a large industry of “creativity enhancement”—programs designed to make people more creative. Some of these programs use insights of basic research. Others represent little more than the intuitions of their inventors. When possible, training should be based on psychological theory and research, rather than guesswork.

SUMMARY

1. **What are some key steps involved in solving problems?** Problem solving involves mentally working to overcome obstacles that stand in the way of reaching a goal. The key steps of problem solving are problem identification, problem definition and representation, strategy construction, organization of information, allocation of resources, monitoring, and evaluation. In everyday experiences, these steps may be implemented flexibly. Various steps may be repeated, may occur out of sequence, or may be implemented interactively.
2. **What are the differences between problems that have a clear path to a solution versus problems that do not?** Although well-structured problems may have clear paths to solution, the route to solution still may be difficult to follow. Some well-structured problems can be solved using algorithms. They may be tedious to implement but are likely to lead to an accurate solution if applicable to a given problem. Computers are likely to use algorithmic

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problem-solving strategies. Humans are more likely to use rather informal heuristics (e.g., means–ends analysis, working forward, working backward, and generate and test for solving problems). When ill-structured problems are solved, the choice of an appropriate problem representation powerfully influences the ease of reaching an accurate solution. Additionally, in solving ill-structured problems, people may need to use more than a heuristic or an algorithmic strategy; insight may be required. Many ill-structured problems cannot be solved without the benefit of insight. There are several alternative views of how insightful problem solving takes place. According to the Gestaltist and the neo-Gestaltist views, insightful problem solving is a special process. It includes more than the sum of its parts and may be evidenced by the suddenness of realizing a solution.

3. **What are some of the obstacles and aids to problem solving?** A mental set (also termed entrenchment) is a strategy that has worked in the past but that does not work for a particular problem that needs to be solved in the present.

   A particular type of mental set is functional fixedness. It involves the inability to see that something that is known to have a particular use also may be used to serve other purposes. Transfer may be either positive or negative. It refers to the carryover of problem-solving skills from one problem or kind of problem to another. Positive transfer across isomorphic problems rarely occurs spontaneously, particularly if the problems appear to be different in content or in context. Incubation follows a period of intensive work on a problem. It involves laying a problem to rest for a while and then returning to it. In this way, subconscious work can continue on the problem while the problem is consciously ignored.
4. **How does expertise affect problem solving?** Experts differ from novices in both the *amount* and the *organization of knowledge* that they bring to bear on problem solving in the domain of their expertise. For experts, many aspects of problem solving may be governed by automatic processes.

   Such automaticity usually facilitates the expert's ability to solve problems in the given area of expertise. When problems involve novel elements requiring novel strategies, however, the automaticity of some procedures actually may impede problem solving, at least temporarily. Expertise in a given domain is viewed mostly from the practice-makes-perfect perspective. Talent, however, should not be ignored and probably contributes much to the differences among experts.
5. **What is creativity, and how can it be fostered?** Creativity involves producing something that is both original and worthwhile. Several factors characterize highly creative individuals. One is extremely high motivation to be creative in a particular field of endeavor (e.g., for the sheer enjoyment of the creative process). A second factor is both nonconformity in violating any conventions that might inhibit the creative work and dedication in maintaining standards of excellence and self-discipline related to the creative work. A third factor in creativity is deep belief in the value of the creative work, as well as willingness to criticize and improve the work. A fourth is careful choice of the problems or subjects on which to focus creative attention.

   A fifth characteristic of creativity is thought processes characterized by both insight and divergent thinking. A sixth factor is risk taking. The final two factors in creativity are extensive knowledge of the relevant domain and profound commitment to the creative endeavor. In addition, the historical context and the domain and field of endeavor influence the expression of creativity.

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THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe the steps of the problem-solving cycle and give an example of each step.
2. What are some of the key characteristics of expert problem solvers?
3. What are some of the insights into problem solving gained through studying computer simulations of problem solving? How might a computer-based approach limit the potential for understanding problem solving in humans?
4. Compare and contrast the various approaches to creativity.
5. Design a problem that would require insight for its solution.
6. Design a context for problem solving that would enhance the ease of reaching a solution.
7. Given what we know about some of the hindrances to problem solving, how could you minimize those hindrances in your handling of the problems you face?
8. Given some of the ideas regarding creativity presented in this chapter, what can you do to enhance your own creativity?

KEY TERMS

algorithms, p. 405
analysis, p. 402
convergent thinking, p. 402
creativity, p. 431
divergent thinking, p. 402
embodied cognition, p. 420
expertise, p. 422
functional fixedness, p. 416
heuristics, p. 406
ill-structured problems, p. 403
incubation, p. 420
insight, p. 410
isomorphic, p. 407
mental set, p. 415
negative transfer, p. 417
positive transfer, p. 418
problem solving, p. 400
problem-solving cycle, p. 402
problem space, p. 405
productive thinking, p. 411
stereotypes, p. 416
synthesis, p. 402
transfer, p. 417
transparency, p. 420
well-structured problems, p. 403

MEDIA RESOURCES

- Explore the following experiment in CogLab:

Lab 50—Monty Hall

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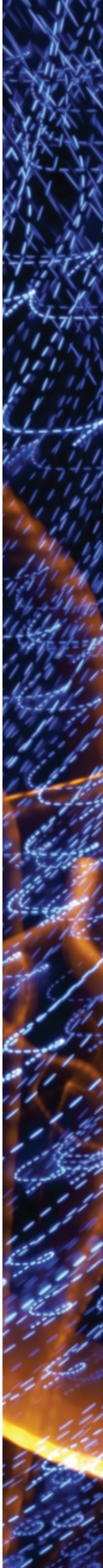
12

Decision Making and Reasoning

CHAPTER OUTLINE

- **Judgment and Decision Making**
  - Classical Decision Theory
    - The Model of Economic Man and Woman
    - Subjective Expected Utility Theory
  - Heuristics and Biases
    - Heuristics
    - Biases
  - Fallacies
  - Gambler's Fallacy and the Hot Hand
  - Conjunction Fallacy
    - Sunk Cost Fallacy
  - Do Heuristics Help Us or Lead Us Astray?
  - Opportunity Costs
  - Naturalistic Decision Making
  - Group Decision Making
    - Benefits of Group Decisions
    - Groupthink
    - Antidotes for Groupthink
  - Neuroscience of Decision Making
- **Deductive Reasoning**
  - What Is Deductive Reasoning?
  - Conditional Reasoning
    - What Is Conditional Reasoning?
    - The Wason Selection Task
    - Conditional Reasoning in Everyday Life
    - Influences on Conditional Reasoning
    - Evolution and Reasoning
  - Syllogistic Reasoning: Categorical Syllogisms
    - What Are Categorical Syllogisms?
    - How Do People Solve Syllogisms?
  - Aids and Obstacles to Deductive Reasoning
    - Heuristics in Deductive Reasoning
    - Biases in Deductive Reasoning
- **Inductive Reasoning**
  - What Is Inductive Reasoning?
  - Causal Inferences
  - Categorical Inferences
  - Reasoning by Analogy
- **An Alternative View of Reasoning**
- **Neuroscience of Reasoning**
- **Key Themes**
- **Summary**
- **Thinking about Thinking: Analytical, Creative, and Practical Questions**
- **Key Terms**
- **Media Resources**

🟥 **COGLAB** The **CogLab** icon directs you to concept-related experiments and labs you can explore. Each CogLab reference includes the Lab title and number for easy access. Go to **CogLab.Cengage.com.**



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Here are some questions we will explore in this chapter:

1. What are some of the strategies that guide human decision making?
2. What are some of the forms of deductive reasoning that people may use, and what factors facilitate or impede deductive reasoning?
3. How do people use inductive reasoning to make causal inferences and to reach other types of conclusions?
4. Are there any alternative views of reasoning?

BELIEVE IT OR NOT

Can a Simple Rule of Thumb Outsmart a Nobel Laureate's Investment Strategy?

If you wanted to invest your money in the stock market, would you rather rely on a Nobel laureate's strategy or on a simple heuristic (which is kind of a rule of thumb)? Researchers (DeMiguel, Garlappi, & Uppal, 2007) compared the levels of success of 14 portfolio management strategies and compared them with the success of the simple 1/*N* heuristic. This heuristic simply suggests that you distribute your assets evenly among a given number of options. That is, each of the *N* options receives 1/*N* of the total investment. Among the other strategies evaluated was Nobel laureate Harry Markowitz's mean variance model, according to which investors should optimize the trade-off between the mean and variance of a portfolio return. Markowitz suggested you minimize your risk and maximize your return by considering several factors, such as that sometimes certain groups of stocks go up in price, whereas others go down (e.g., if the oil price goes up, airline profits will go down). The researchers found that the simple 1/*N* heuristic actually outperformed all 14 other models. In this chapter, you will learn more about how humans make decisions and what shortcuts (heuristics) they use when they are faced with uncertainty or more information than they can process.

Let's start this chapter with a puzzle. Read the following description in *Investigating Cognitive Psychology: The Conjunction Fallacy* and rate the likelihood of the presented statements.

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The Conjunction Fallacy

Linda is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice and also participated in antinuclear demonstrations.

Based on the preceding description, list the likelihood that the following statements about Linda are true (0 means completely unlikely and 100 means totally likely):

(a) Linda is a teacher in elementary school.
(b) Linda works in a bookstore and takes yoga classes.
(c) Linda is active in the feminist movement.
(d) Linda is a psychiatric social worker.
(e) Linda is a member of the League of Women Voters.
(f) Linda is a bank teller.
(g) Linda is an insurance salesperson.
(h) Linda is a bank teller and is active in the feminist movement.

(Tversky & Kahneman, 1983, p. 297).

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If you are like 85% of the people Tversky and Kahneman (1983) studied, you rated the likelihood of item (h) as greater than the likelihood of item (f). Imagine a huge convention hall filled with the entire population of bank tellers. Now think about how many of them would be at a hypothetical booth for feminist bank tellers—a subset of the entire population of bank tellers. If Linda is at the booth for feminist bank tellers, she must, by definition, be in the convention hall of bank tellers. Hence, the likelihood that she is at the booth (i.e., she is a feminist bank teller) cannot logically be greater than the likelihood that she is in the convention hall (i.e., she is a bank teller). Nonetheless, given the description of Linda, we intuitively feel more likely to find her at the booth within the convention hall than in the entire convention hall, which makes no sense. This intuitive feeling is an example of a **fallacy**—erroneous reasoning—in judgment and reasoning.

In this chapter, we consider many ways in which we make judgments and decisions and use reasoning to draw conclusions. The first section deals with how we make choices and judgments. **Judgment and decision making** are used to select from among choices or to evaluate opportunities. Afterward, we consider various forms of reasoning. The goal of reasoning is to draw conclusions, either deductively from principles or inductively from evidence.

Judgment and Decision Making

In the course of our everyday lives, we constantly are making judgments and decisions. One of the most important decisions you may have made is whether and where to go to college. Once in college, you still need to decide on which courses to take. Later on, you may need to choose a major field of study. You make decisions about friends, dates, how to relate to your parents, how to spend money, and countless other things. How do you go about making these decisions?

Classical Decision Theory

The earliest models of how people make decisions are referred to as *classical decision theory*. Most of these models were devised by economists, statisticians, and philosophers, not by psychologists. Hence, they reflect the strengths of an economic perspective. One such strength is the ease of developing and using mathematical models for human behavior.

The Model of Economic Man and Woman

Among the early models of decision making crafted in the 20th century was that of *economic man and woman*. This model assumed three things:

1. Decision makers are fully informed regarding all possible options for their decisions and of all possible outcomes of their decision options.
2. They are infinitely sensitive to the subtle distinctions among decision options.
3. They are fully rational in regard to their choice of options (Edwards, 1954; see also Slovic, 1990).

Although this model may seem dated, it prevails in many theories of economics. And people often assume that their thinking is the rational kind proposed by this model, even when it isn't. That is, they believe they decide according to the model of economic man and woman, although they do not and can not.

The assumption of infinite sensitivity means that people can evaluate the difference between two outcomes, no matter how subtle the distinctions among options may be.

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The assumption of rationality means that people make their choices to maximize something of value, whatever that something may be.

Consider an example of how this model works. Suppose that a decision maker is considering which of two smartphones to buy. The decision maker, according to this model, will consider every aspect of each phone. The shopper will next decide on some objective basis how favorable each phone is on each aspect. The shopper then will weigh objectively each of the aspects in terms of how important it is. The favorability ratings will be multiplied by the weights. Then an overall averaged rating will be computed, taking into account all of the data. The shopper then will buy the smartphone with the best score. A great deal of economic research has been based on this model.

Subjective Expected Utility Theory

An alternative model makes greater allowance for the psychological makeup of each individual decision maker. According to *subjective expected utility theory,* the goal of human action is to seek pleasure and avoid pain. According to this theory, when people make decisions, they will seek to maximize pleasure (referred to as positive utility) and to minimize pain (referred to as negative utility). In doing so, however, we calculate two things. One is **subjective utility**, which is a calculation based on the individual's judged weightings of utility (value), rather than on objective criteria. The second is **subjective probability**, which is a calculation based on the individual's estimates of likelihood, rather than on objective statistical computations. The difference between this model and the former one is that the ratings and weights are subjective, whereas in the former model they are supposedly objective.

Scientists soon noticed that human decision making is more complex than even this modified theory implies. In particular, when did you seriously consider every aspect of a decision, rate each possible choice, weigh the choice, and then use your favorability ratings and weights to compute an averaged evaluation of each of the choices? Probably not recently.

Heuristics and Biases

The world is full of information and different stimuli. We need to filter out the information we need from the many different pieces of information available to us to function properly and not get overwhelmed,. The same is true for decision making. To be able to make a decision within a reasonable time frame, we need to reduce the available information to a manageable amount. Heuristics help us achieve this goal and at the same time decrease our efforts by allowing us to examine fewer cues or deal with fewer pieces of information (Shah & Oppenheimer, 2008). Sometimes, however, our thinking also gets biased by our tendencies to more simply make decisions. Heuristics and biases—mental shortcuts—not only lighten the cognitive load of making decisions but also allow for a much greater chance of error. We will explore both heuristics and biases in more detail in the next section.

Heuristics

In the following sections, we discuss several heuristics people use in their daily decision making. **Heuristics** are mental shortcuts that lighten the cognitive load of making decisions.

Satisficing As early as the 1950s some researchers began to challenge the notion of unlimited rationality. These researchers recognized that humans do not always make ideal decisions and that we usually include subjective considerations in our decisions. We show **bounded rationality**—we are rational, but within limits (Simon, 1957).

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Classical decision theory suggested that people optimize their decisions, but researchers began to realize that we have only limited resources and time to make a decision, so we often try to get as close as possible to optimizing, without actually optimizing.

One of the first heuristics that was formulated by researchers is termed *satisficing* (Simon, 1957). In **satisficing**, we consider options one by one, and then we select an option as soon as we find one that is satisfactory or just good enough to meet our minimum level of acceptability. When limited working memory resources are available, the use of satisficing for making decisions may be increased (Chen & Sun, 2003). Satisficing is used in industrial contexts in which too much information can impair the quality of decisions, as in the selection of suppliers in electronic marketplaces (Chamodrakas, Batis, & Martakos, 2010).

People use satisficing strategies in their everyday lives as well. A lot of people know keyboard shortcuts on the computer, for example, and yet they often do not use them, although those shortcuts are an efficient way to use many programs. Researchers believe that satisficing (i.e., using any strategy that works to accomplish a goal, even if it is not the most effective strategy) plays a role in computer users' not applying shortcuts (Tak, Westendorp, & van Rooij, 2013).

The appropriateness of this strategy will vary with the circumstance. For example, satisficing might be a reasonable strategy if you are in a hurry to buy a pack of gum and then catch a train or a plane, but it is a poor strategy for diagnosing a disease.

With respect to decision making, people generally fall into two groups: Satisficers consider options until they have found one that is good enough for them. Maximizers try to consider every single option before choosing the best one. Think about buying a car: Depending on which strategy you employ, you can either search for a potential car until you have found one that satisfies your criteria, or you can try out every single car that is an option for you and only then make a purchase decision. Research has shown that while both maximizers and satisficers may end up making good choices (although maximizers usually make objectively better decisions), maximizers usually end up being less happy with their choices than satisficers (Polman, 2010). Maximizers also tend to be more overconfident in their decisions than satisficers. In a study predicting the results of the FIFA soccer World Cup in 2010 (Jain, Bearden, & Filipowicz, 2013), maximizers predicted the results less accurately than satisficers, although they were more confident in their ability to predict the results.

In another study, investors who consider their investment astuteness to be above average (i.e., who are overconfident) engage in more trades than others, which ultimately can lower their returns because they incur more transaction costs. Ironically, it is thus plausible that maximizers end up faring worse in some economic settings than do satisficers (Glaser & Weber, 2007).

Elimination by Aspects When we have more alternatives than we can consider in the time available, we sometimes use a different strategy (Tversky, 1972a, 1972b). In a process of **elimination by aspects**, we eliminate alternatives by focusing on aspects of each alternative, one at a time, instead of mentally manipulating all the weighted attributes of all the

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According to Herbert Simon, people often satisfice when they make important decisions, such as which car to buy. They decide based on the first acceptable alternative that comes along.

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available options. If you are trying to decide which college to attend, the process of elimination by aspects might look like this:

- focus on one aspect (attribute) of the various options (the cost of going to college);
- form a minimum criterion for that aspect (tuition must be under $20,000 per year);
- eliminate all options that do not meet that criterion (e.g., Stanford University is more than $30,000 and would be eliminated);
- for the remaining options, select a second aspect for which we set a minimum criterion by which to eliminate additional options (the college must be on the West Coast); and
- continue using a sequential process of elimination of options by considering a series of aspects until a single option remains (Dawes, 2000).

Here is another example of elimination by aspects: In choosing a car to buy, we may focus on total price as an aspect. We may choose to dismiss factors, such as maintenance costs, insurance costs, or other factors that realistically might affect the money we will have to spend on the car in addition to the sale price. Once we have weeded out the alternatives that do not meet our criterion, we choose another aspect. We set a criterion value and weed out additional alternatives. We continue in this way. We weed out more alternatives, one aspect at a time, until we are left with a single option. In practice, it appears that we may use some elements of elimination by aspects or satisficing to narrow the range of options to just a few. Then we use more thorough and careful strategies. Examples would be those suggested by subjective expected utility theory. They can be useful for selecting among the few remaining options (Payne, 1976).

Using Probabilities to Make Decisions We often use mental shortcuts and even biases that limit and sometimes distort our ability to make rational decisions. One of the key ways in which we use mental shortcuts centers on our estimations of probability. Consider some of the strategies used by statisticians when calculating probability. They are shown in Table 12.1 ■.

Another kind of probability is *conditional probability,* which is the likelihood of one event, given another. For example, you might want to calculate the likelihood of receiving an *A* for a cognitive psychology course, given that you receive an *A* on the final exam. The formula for calculating conditional probabilities in light of evidence is known as *Bayes's theorem*. It is quite complex, so most people do not use it in everyday reasoning

Table 12.1 Using Probabilities to Make Decisions

Hypothetical Example	Calculation of Probability
Lee is one of 10 highly qualified candidates applying for one scholarship. What are Lee's chances of getting the scholarship?	Lee has a 0.1 chance of getting the scholarship.
If Lee is one of 10 highly qualified scholarship students applying for one scholarship, what are Lee's chances of not getting the scholarship?	1–0.1 = 0.9 Lee has a 0.9 chance of not getting the scholarship.
Lee's roommate and Lee are among 10 highly qualified scholarship students applying for one scholarship. What are the chances that one of the two will get the scholarship?	0.1 + 0.1 = 0.2 There is a 0.2 chance that one of the two roommates will get the scholarship.

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situations. Nonetheless, such calculations are essential to evaluating scientific hypotheses, forming realistic medical diagnoses, analyzing demographic data, and performing many other real-world tasks. (For a highly readable explanation of Bayes's theorem, see Eysenck & Keane, 2010, pp. 499–500.)

Representativeness Heuristic Before you read about representativeness, try the following problem from Kahneman and Tversky (1972):

> All the families having exactly six children in a particular city were surveyed. In 72 of the families, the exact order of births of boys and girls was G B G B B G (G, girl; B, boy).
>
> What is your estimate of the number of families surveyed in which the exact order of births was B G B B B B?

Most people judging the number of families with the B G B B B B birth pattern estimate the number to be less than 72. Actually, the best estimate of the number of families with this birth order is 72, the same as for the G B G B B G birth order. The expected number for the second pattern would be the same because the gender for each birth is independent (at least, theoretically) of the gender for every other birth. For any one birth, the chance of a boy (or a girl) is one of two. Thus, any particular pattern of births is equally likely $(1/2)^6$, even B B B B B B or G G G G G G.

Why do many of us believe some birth orders to be more likely than others? In part, the reason is that we use the heuristic of representativeness. In **representativeness,** we judge the probability of an uncertain event according to the following:

1. how obviously it is similar to or representative of the population from which it is derived; and
2. the degree to which it reflects the salient features of the process by which it is generated (such as randomness; see also Fischhoff, 1999; Johnson-Laird, 2000, 2004).

For example, people believe that the first birth order is more likely because (1) it is more representative of the number of females and males in the population; and (2) it looks more like a random order than does the second birth order. In fact, of course, either birth order is equally likely to occur by chance.

Similarly, suppose people are asked to judge the probability of flips of a coin yielding the sequence H T H H T H (H, heads; T, tails). Most people will judge it as higher than they will if asked to judge the sequence H H H H T H. If you expect a sequence to be random, you tend to view as more likely a sequence that "looks random." Indeed, people often comment that the numbers in a table of random numbers "don't look random." The reason is that people underestimate the number of runs of the same number that will appear wholly by chance. We frequently reason in terms of whether something appears to represent a set of accidental occurrences, rather than actually considering the true likelihood of a given chance occurrence. This tendency makes us more vulnerable to the machinations of magicians, charlatans, and con artists. Any one of them may make much of their having predicted the realistic probability of a nonrandom looking event. For example, in 1 out of 10 cases, 2 people in a group of 40 (e.g., in a classroom or a small nightclub audience) will share a birthday (the same month and day). In a group of 14 people, the odds are better than even that two people will have birthdays within a day of each other (Krantz, 1992).

That we frequently rely on the representativeness heuristic may not be terribly surprising. It is easy to use and often works. For example, suppose we have not heard a weather report before stepping outside. We informally judge the probability that it will

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rain. We base our judgment on how well the characteristics of this day (e.g., the month of the year, the area in which we live, and the presence or absence of clouds in the sky) represent the characteristics of days on which it rains. Another reason that we often use the representativeness heuristic is that we mistakenly believe that small samples (e.g., of events, of people, of characteristics) resemble in all respects the whole population from which the sample is drawn (Tversky & Kahneman, 1971). We particularly tend to underestimate the likelihood that the characteristics of a small sample (e.g., the people whom we know well) of a population inadequately represent the characteristics of the whole population.

We also tend to use the representativeness heuristic more frequently when we are highly aware of anecdotal evidence based on a very small sample of the population. This reliance on anecdotal evidence has been referred to as a "man who" argument (Nisbett & Ross, 1980). When presented with statistics, we may refute those data with our own observations of, "I know a man who . . . " For example, faced with statistics on coronary disease and high cholesterol diets, someone may counter with, "I know a man who ate whipped cream for breakfast, lunch, and dinner, smoked two packs of cigarettes a day, and lived to be 110 years old. He would have kept going but he was shot through his perfectly healthy heart by a jealous lover."

Sometimes, people make decisions on the basis of small samples of data because they assume that their sample is representative. For example, you may ask a few friends their opinion of something and, if they agree with you and each other, assume you are on the right track. In this case, the sample was probably too small and limited, but because of the use of the representativeness heuristic, the conclusions you draw may well be wrong.

One reason that people misguidedly use the representativeness heuristic is because they fail to understand the concept of base rates. **Base rate** refers to the prevalence of an event or characteristic within its population of events or characteristics. In everyday decision making, people often ignore base rate information, but it is important to effective judgment and decision making. In many occupations, the use of base rate information is essential for adequate job performance. For example, suppose a doctor was told that a 10-year-old boy was suffering chest pains. The doctor would be much less likely to worry about an incipient heart attack than if the doctor were told that a 60-year-old man had the identical symptom. Why? Because the base rate of heart attacks is much higher in 60-year-old men than in 10-year-old boys. Of course, people use other heuristics as well. People can be taught how to use base rates to improve their decision making (Gigerenzer, 1996; Koehler, 1996).

Availability Heuristic Most of us at least occasionally use the **availability heuristic**, in which we make judgments on the basis of how easily we can call to mind what we perceive as relevant instances of a phenomenon (Tversky & Kahneman, 1973; see also Fischhoff, 1999; Sternberg, 2000). For example, consider the letter *R*. Are there more words in the English language that begin with the letter *R* or that have *R* as their third letter? Most respondents say that more words begin with the letter *R* (Tversky & Kahneman, 1973). Why? Because generating words beginning with the letter *R* is easier than generating words having *R* as the third letter. In fact, more English language words have *R* as their third letter. The same happens to be true of some other letters as well, such as *K, L, N,* and *V.*

The availability heuristic also has been observed in regard to everyday situations. In one study, married partners individually stated which of the two partners performed a larger proportion of 20 different household chores (Ross & Sicoly, 1979). These tasks included mundane chores such as grocery shopping or preparing breakfast. Each partner stated that he or she more often performed about 16 of the 20 chores. Suppose each partner was correct. Then, to accomplish 100% of the work in a household, each partner would have to perform 80% of the work. Similar outcomes emerged from questioning members of college basketball teams and joint participants in laboratory tasks.

Although clearly 80% + 80% does not equal 100%, we can understand why people may engage in using the availability heuristic when it confirms their beliefs about themselves. People, however, also use the availability heuristic when its use leads to a logical fallacy that has nothing to do with their beliefs about themselves. Two groups of participants were asked to estimate the number of words of a particular form that would be expected to appear in a 2,000-word passage. For one group the form was _ _ _ _ing (i.e., seven letters ending in *ing*). For the other group the form was _ _ _ _ _n_ (i.e., seven letters with *n* as the second to the last letter). Clearly, there cannot be more seven-letter words ending in *-ing* than seven letter words with *n* as the second to the last letter. But the greater availability of the former group of letters led to estimates of probability that were more than twice as high than for the latter group of letters (Tversky & Kahneman, 1983).

If you use lots of social media in your daily life, the availability heuristic may actually affect the way you perceive your own life: A study of Facebook users found that those who had been using Facebook for a long time and spent a significant amount of time on Facebook each week felt that others were happier and had better lives than they themselves did. This is because Facebook users post events selectively on Facebook and try to present themselves in a favorable way. Thus, a good number of positive events are posted which in turn stick in our mind (are "available") and are used when we compare our own life with that of others (Chou & Edge, 2012).

Anchoring A heuristic related to availability is the *anchoring and adjustment heuristic,* by which people adjust their evaluations of things by means of certain reference points called *end anchors.* Before you read on, quickly (in less than 5 seconds) calculate in your head the answer to the following problem:

$$8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$$

Now, quickly calculate your answer to the following problem:

$$1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8$$

Two groups of participants estimated the product of one set or the other set of the preceding eight numbers (Tversky & Kahneman, 1974). The median (middle) estimate for the participants given the first sequence was 2,250. For the participants given the second sequence, the median estimate was 512. (The actual product is 40,320 for both.) The two products are the same, as they must be because the numbers are exactly the same (applying the commutative law of multiplication). Nonetheless, people provide a higher estimate for the first sequence than for the second because their computation of the anchor—the first few digits multiplied by each other—renders a higher estimate from which they make an adjustment to reach a final estimate. Furthermore, the adjustment people make in response to an anchor is bigger when the anchor is rounded than when it seems to be a precise value. For example, when the price of a television set is given as $3,000, people adjust their estimate of its production costs more than when the price is given as $2,991 (Janiszewski & Uy, 2008). Anchoring effects occur in a variety of settings, for example at art auctions, where the price of paintings is anchored by the price the painting achieved in prior sales, or monthly economic forecasts, which are anchored toward the past month (Beggs & Graddy, 2009; Campbell & Sharpe, 2009).

In everyday life, the anchoring heuristic potentially can have a large impact on people's charitable giving: When people are informed about other donations, they often

Although riding a car is statistically much more risky than riding in a plane, people often feel less safe in a plane, in part because of the availability heuristic. People hear about every major U.S. plane crash that takes place, but they hear about relatively few car accidents.

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follow what the others did, anchoring their donations on the basis of these other donations (Hysenbelli, Rubaltelli, & Rumiati, 2013). Thus, if you are trying to raise money, you probably will raise more money if you point out large sums that others are donating who are in the peer group of the target giver.

Framing Another consideration in decision theory is the influence of *framing effects,* in which the way that the options are presented influences the selection of an option (Tversky & Kahneman, 1981). For instance, we tend to choose options that demonstrate risk aversion when we are faced with an option involving potential gains. That is, we tend to choose options offering a small but certain gain rather than a larger but uncertain gain, unless the uncertain gain is either tremendously greater or only modestly less than certain. The first example in *Investigating Cognitive Psychology: Framing Effects* is only slightly modified from one used by Tversky and Kahneman (1981).

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INVESTIGATING COGNITIVE PSYCHOLOGY

Framing Effects

Suppose that you were told that 600 people were at risk of dying of a particular disease. Vaccine A could save the lives of 200 of the people at risk. With Vaccine B, there is a 0.33 likelihood that all 600 people would be saved, but there is also a 0.66 likelihood that all 600 people will die. Which option would you choose? Explain how you made your decision.

We tend to choose options that demonstrate risk seeking when we are faced with options involving potential losses. That is, we tend to choose options offering a large but uncertain loss rather than a smaller but certain loss (as is the case for Vaccine B), unless the uncertain loss is either tremendously greater or only modestly less than certain. Here is an interesting example.

Now consider another set of vaccines: For the 600 people at risk of dying of a particular disease, if Vaccine C is used, 400 people will die. However, if Vaccine D is used, there is a 0.33 likelihood that no one will die and a 0.66 likelihood that all 600 people will die. Which option would you choose?

In the preceding situations, most people will choose Vaccine A and Vaccine D.

Now, have a look at the table below and compare:

- The number of people whose lives will be lost or saved by using Vaccines A or C.
- The number of people whose lives will be lost or saved by using Vaccines B or D.

Vaccine	Number of people who will survive and likelihood of this event	Number of people who will die and likelihood of this event	
A	200 people – 1.0	400 people – 1.0	More people choose Option A or Option B
B	600 – 0.33	600 people – 0.66	
C	200 people – 1.0	400 people – 1.0	Most people choose Option D over Option C
D	600 people – 0.33	600 people – 0.66	

The expected value is identical for Vaccines A and C; it is also identical for Vaccines B and D. But the vaccines people chose as their first choice differed depending on the way the options were presented to them. What is different is whether the choices were framed in terms of losses or gains. In the first example, Vaccine A has been framed in terms of gains (i.e., 200 people will survive). This framing leads to the adoption of a risk-aversion strategy (i.e., people would rather save 200 people's lives than no one's life). In the second example, Vaccine C has been framed in terms of losses (i.e., 400 people will die for sure). This framing leads to the adoption of a risk-taking strategy (i.e., people would rather take a 66.6% chance that 600 people will die than take for granted the sure death of 400 people).

Our predilection for risk aversion versus risk seeking leads us to quite different choices based on the way in which a decision is framed, even when the actual outcomes of the choices are the same.

Framing effects have public relevance. Messages from politicians, political parties, and other stakeholders can be framed in different ways and therefore take on a different connotation. A message about the Ku Klux Klan, for example, can be framed either as a free speech issue or as a public safety issue. Framing effects are less persuasive when they come from sources of low credibility (Druckman, 2001). Perhaps not surprisingly, the feedback of close friends has an impact on the framing effect—whether our friends cheer on a framed option or make negative comments about it influences how effective the framing is (Sip et al., 2015). ■ See also Lab 51, Risky Decisions, in CogLab to learn more about framing effects.

Biases

In the next section, we discuss several biases that frequently occur when people make decisions: illusory correlation, overconfidence, and hindsight bias.

Illusory Correlation We are predisposed to see particular events or attributes and categories as going together, even when they do not. This phenomenon is called **illusory correlation** (Hamilton & Lickel, 2000). In the case of events, we may see spurious cause–effect relationships. In the case of attributes, we may use personal prejudices to form and use stereotypes (perhaps as a result of using the representativeness heuristic). For example, suppose we expect people of a given political party to show particular intellectual or moral characteristics. The instances in which people show those characteristics are more likely to be available in memory and to be recalled more easily than are instances that contradict our biased expectations. In other words, we perceive a correlation between the political party and the particular characteristics.

Illusory correlation even may influence psychiatric diagnoses based on projective tests such as the Rorschach and the Draw-a-Person tests (Chapman & Chapman, 1967, 1969, 1975). Researchers suggested a false correlation in which particular diagnoses would be associated with particular responses. For example, they suggested that people diagnosed with paranoia tend to draw people with large eyes more than do people with other diagnoses (which is not true). So, what happened when individuals expected to observe a correlation between a drawing with large eyes and the associated diagnosis of paranoia? They tended to see the illusory correlation, although no actual correlation existed.

Overconfidence Another common error is **overconfidence**—an individual's overvaluation of her or his own skills, knowledge, or judgment. For example, people answered 200 two-alternative statements, such as "Absinthe is (a) a liqueur, (b) a precious stone." (Absinthe is a licorice-flavored liqueur.) People were asked to choose the correct answer and to state the probability that their answer was correct (Fischhoff, Slovic, & Lichtenstein, 1977). People were overconfident. For example, when people were 100% confident in their answers, they were right only 80% of the time. In general, people tend to overestimate the accuracy of their judgments (Kahneman & Tversky, 1996). Why are people overconfident? One reason is that people may not realize how little they know. Another is that they may not realize that their information comes from unreliable sources (Carlson, 1995; Griffin & Tversky, 1992).

People also tend to be biased in favor of their own attitudes and beliefs. For example, if someone believes that people who have business degrees are particularly well versed in business matters, they may pay particular attention to news articles and facts that confirm their belief. They also generate evidence and test their ideas in a way to conform to their beliefs. This is called *myside bias* (Stanovich, West, & Toplak, 2013; Wolfe & Britt, 2008). You might think that myside bias is related to intelligence such that people who are more academically intelligent are more able and willing to sort through evidence in a nonbiased way, but it actually has been shown that there is little relation between susceptibility to myside bias and intelligence (Stanovich, West, & Toplak, 2013).

People sometimes make poor decisions as a result of overconfidence. These decisions are based on inadequate information and ineffective decision-making strategies. Why we tend to be overconfident in our judgments is not clear. One simple explanation is that we prefer not to think about being wrong (Fischhoff, 1988).

Businesses sometimes use our tendencies toward overconfidence to their own advantage. Think about the American cell phone market, for example. Many contracts consist of a monthly fee that includes usage of a certain amount of airtime minutes. If a person

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exceeds this amount, he or she will incur steep charges. There are good reasons for such a contract model, but from the company's point of view, not from the consumer's point of view. Consumers tend to overestimate their usage of minutes, so they are willing to pay for a high minute usage in advance. At the same time, they are confident they will not go over their limit, so they do not even realize the high costs they will incur if they exceed their free airtime minutes, until they actually discover they have gone over (Grubb, 2009).

Hindsight Bias **Hindsight bias** occurs when we look at a situation retrospectively, and we believe we easily could have seen in advance all the signs and events that led up to a particular outcome (Fischhoff, 1982; Wasserman, Lempert, & Hastie, 1991). For example, suppose people are asked to predict the outcomes of psychological experiments in advance of the experiments. People rarely are able to predict the outcomes at better than chance levels. When people are told of the outcomes of psychological experiments, however, they frequently comment that these outcomes were obvious and easily could have been predicted in advance. Similarly, when intimate personal relationships are in trouble, people often fail to observe signs of the difficulties until the problems reach crisis proportions. By then, it may be too late to save the relationship. In retrospect, people may ask themselves, "Why didn't I see it coming? It was so obvious! I should have seen the signs."

In the hindsight bias, people misremember their original judgment of a situation in the face of the outcome of that situation. Thus, it is a form of memory distortion. Not surprisingly, therefore, the tendency toward this bias is negatively correlated with working-memory capacity (Calvillo, 2014): People with poorer working-memory capacity are more susceptible to the bias.

Hindsight bias hinders learning because it impairs one's ability to compare one's expectations with the outcome—if one always expected the outcome that eventually happened, one thinks there is nothing to learn! And, indeed, studies show that investment bankers' performance suffers when they exhibit a strong hindsight bias. Curiously, experience does not reduce the bias (Biais & Weber, 2009).

Fallacies

Heuristics and fallacies often are studied together because they go hand in hand. The application of a heuristic to make a decision may lead to fallacies in thinking. Therefore, when we discuss some fallacies, we refer back to some of the heuristics in association with which they often occur.

Gambler's Fallacy and the Hot Hand

Gambler's fallacy is a mistaken belief that the probability of a given random event, such as winning or losing at a game of chance, is influenced by previous random events. For example, a gambler who loses five successive bets may believe that a win is therefore more likely the sixth time. He feels that he is "due" to win. In truth, of course, each bet (or coin toss) is an independent event that has an equal probability of winning or losing. The gambler is no more likely to win on the 6th bet than on the 1st bet—or even on the 1001st. Gambler's fallacy is an example of the representative heuristic gone awry: One believes that the pattern representative of past events is now likely to change.

Gender differences emerge in gambling behavior. On average, men tend to be more risk prone than women, to spend more money on lottery tickets, to display more overconfidence when gambling, and generally to have a higher likelihood of being problem gamblers. Recent research has extended these findings of gender differences to the gambler's fallacy by collecting data about Danish lotto players. Men were significantly more likely to change their lotto numbers based on the previous week's drawn numbers (i.e., they chose numbers different from the ones that had just been drawn) than were women. Thus, the men were more likely than the women to exhibit gambler's fallacy (Suetens & Tyran, 2012).

A tendency opposite to that of gambler's fallacy is called the *hot hand effect*. It refers to a belief that a certain course of events will continue. Apparently, both professional and amateur basketball players, as well as their fans, believe that a player's chances of making a basket are greater after making a previous shot than after missing one. However, the statistical likelihoods (and the actual records of players) show no such tendency (Gilovich, Vallone, & Tversky, 1985; see also Roney & Trick, 2009). Shrewd players take advantage of this belief and closely guard opponents immediately after they have made baskets. The reason is that the opposing players will be more likely to try to get the ball to these perceived "streak shooters."

Conjunction Fallacy

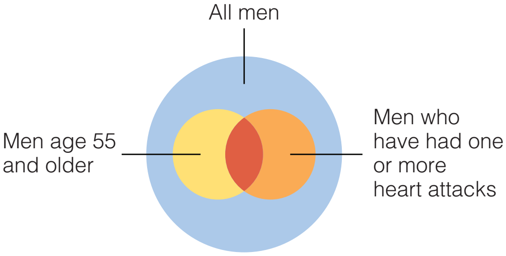
Do you remember the experiment described in the section on the availability heuristic in which people were asked to judge how often the form _ _ _ _ing (i.e., seven letters ending in –*ing*) or _ _ _ _ _n_ (i.e., seven letters with *n* as the second to the last letter) appears in a passage? The availability heuristic might lead to the conjunction fallacy. In the *conjunction fallacy,* an individual gives a higher estimate for a subset of events (e.g., the instances of *ing*) than for the larger set of events containing the given subset (e.g., the instances of *n* as the second to the last letter). This fallacy also is illustrated in the chapter-opening *Investigating Cognitive Psychology* box regarding Linda.

The representativeness heuristic may induce individuals to engage in the conjunction fallacy during probabilistic reasoning (Tversky & Kahneman, 1983; see also Dawes, 2000). Tversky and Kahneman asked college students:

> 1. Please give your estimate of the following values: What percentage of the men surveyed [in a health survey] have had one or more heart attacks?
> 2. What percentage of the men surveyed both are over 55 years old and have had one or more heart attacks? (1983, p. 308)

The mean estimates were 18% for the first question and 30% for the second question. In fact, 65% of the respondents gave higher estimates for the latter, although the group of men over 55 years of age is clearly a subset of the group including men of all ages (see also Figure 12.1 ■). However, people do not always engage in the conjunction fallacy. Only 25% of respondents gave higher estimates for the latter question than for the former when the questions were rephrased as frequencies rather than as percentages (e.g., "how many of the 1,000 men surveyed have had one or more heart attacks?"). The way statistical information is presented influences how likely it is that people draw the correct conclusions (see also Gigerenzer & Hoffrage, 1995).

An interesting phenomenon is that people who subscribe to conspiracy theories (e.g., that the AIDS virus was created in a lab to control population growth) or who believe in the paranormal tend to be more susceptible to the conjunction fallacy (Rogers at al., 2009, 2011). A study assessing participants' beliefs in conspiracy theories subsequently also assessed the people's susceptibility to the conjunction fallacy (Brotherton & French, 2014). People who subscribed more strongly to conspiracy theories also made more



■ **Figure 12.1 Conjunction Fallacy.** The diagram shows (a) all men surveyed, (b) men over 55 who were surveyed, and (c) men who have had heart attacks. The proportion of men surveyed who are both over 55 *and* who have had a heart attack must be lower than the percentage of surveyed men who are merely over 55.

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reasoning mistakes reflecting the conjunction fallacy. The researchers suspect that this susceptibility may be because people who believe in conspiracies often do not believe that coincidences are the result of chance events. Rather, they see causal relationships between unrelated events. ■ To further explore conjunction fallacy, see Lab 52, Typical Reasoning, in CogLab.

Sunk Cost Fallacy

An error in judgment that is quite common in people's thinking is the *sunk cost fallacy* (Dupuy, 1998, 1999; Strough et al., 2008). This fallacy represents the decision to continue to invest in something simply because one has invested in it before and one hopes to recover one's investment. For example, suppose you bought a car. It is a lemon. You have already invested thousands of dollars in getting it fixed. Now another major repair is necessary. You have no reason to believe that this additional repair really will be the last in the string of repairs. You think about how much money you have spent on repairs and reason that you need to do the additional repair to justify past amounts already spent. So you do the repair rather than buy a new car. You have just committed the sunk cost fallacy. The problem is that you already have lost the money on those repairs. Throwing more money into the repairs will not get that money back. Your best bet may be to view the money already spent on repairs as a "sunk cost" and then buy a new car.

Similarly, suppose you go on a two-week vacation. You are having a miserable time. Should you go home a week early? You decide not to, thereby attempting to justify the investment you have already made in the vacation. Again, you have committed the sunk cost fallacy. Instead of viewing the money simply as lost on an unfortunate decision, you have decided to throw more money away. But you do so without any hope that the vacation will get any better.

Do Heuristics Help Us or Lead Us Astray?

Heuristics do not always lead to wrong judgments or poor decisions (Cohen, 1981). Indeed, we use these mental shortcuts because they are so often right. Sometimes, they are amazingly simple ways of drawing sound conclusions. For example, a simple heuristic, *take-the-best,* can be amazingly effective in decision situations (Gigerenzer & Brighton, 2009; Gigerenzer & Goldstein, 1996; Marsh, Todd, & Gigerenzer, 2004). The rule is simple: Identify the single most important criterion to you when making a decision. For example, when you choose a new automobile, the most important factor might be good gas mileage, safety, or appearance. Make your choice on the basis of that attribute.

On its face, this heuristic would seem to be inadequate. Nonetheless, it often leads to very good decisions. It produces even better decisions, in many cases, than far more complicated heuristics. Thus, heuristics can be used for good as well as for bad decision making. Indeed, when we take people's goals into account, heuristics often are amazingly effective (Evans & Over, 1996).

The take-the-best heuristic belongs to a class of heuristics called *fast-and-frugal heuristics* (FFH). As the name implies, this class of heuristics is based on a small fraction of information, and decisions using the heuristics are made rapidly. These heuristics set a standard of rationality that considers constraints, including, time, information, and cognitive capacity (Bennis & Pachur, 2006; Gigerenzer, Todd, & the ABC Research Group, 1999). Furthermore, these models consider the lack of optimum solutions and environments in which the decision is taking place. As a result, these heuristics provide a good description of decision making during sports.

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Fast-and-frugal heuristics can form a comprehensive description of how people behave in a variety of contexts. These behaviors vary from lunch selections to how physicians decide whether to prescribe medication for depression, to making business decisions (Gigerenzer & Gaissmaier, 2011; Goldstein & Gigerenzer, 2009; Scheibehenne, Miesler, & Todd, 2007).

The work on heuristics and biases shows the importance of distinguishing between intellectual competence and intellectual performance as it manifests itself in daily life. Even probability and statistics experts can find themselves falling into faulty patterns of judgment and decision making in their everyday lives. People may be intelligent in a conventional, test-based sense. Yet they may show exactly the same biases and faulty reasoning that someone with a lower test score would show. People often fail to fully utilize their intellectual competence in their daily life. There can even be a wide gap between the two (Stanovich, 2010). Thus, if we wish to be intelligent in our daily lives and not just on tests, we have to be street smart. In particular, we must be mindful of applying our intelligence to the problems that continually confront us.

Opportunity Costs

Opportunity costs are the prices paid for availing oneself of certain opportunities. Taking opportunity costs into account is important when judgments are made. For example, suppose you see a great job offer in San Francisco. You always wanted to live there. You are ready to take it. Before you do, you need to ask yourself a question: What other things will you have to give up to take advantage of this opportunity? An example of something you will have to forego is having a large apartment or house. Another might be the chance to live in a place where you probably do not have to worry about earthquakes. Any time you take advantage of an opportunity, there are opportunity costs. They may, in some cases, make what looked like a good opportunity look like not such a great opportunity at all. Ideally, you should try to look at these opportunity costs in an unbiased way.

Naturalistic Decision Making

Many researchers contend that decision making is a complex process that cannot be reproduced adequately in the laboratory because real decisions are frequently made in high-stakes situations. For instance, the mental state and cognitive pressure experienced by an emergency room doctor encountering a patient is difficult to reproduce outside a clinical setting.

This criticism has led to the development of a field of study that is based on decision making in natural environments (naturalistic decision making). Much of the research completed in this area is from professional settings, such as hospitals or nuclear plants (Carroll, Hatakenaka, & Rudolph, 2006; Galanter & Patel, 2005; Roswarski, & Murray, 2006). These situations share a number of features, including the challenges of ill-structured problems, changing situations, high risk, time pressure, and sometimes, a team environment (Orasanu & Connolly, 1993). A number of models are used to explain performance in these high-stakes situations. These models allow for the consideration of cognitive, emotional, and situational factors of skilled decision makers; they also provide a framework for advising future decision makers (Klein, 1997; Lipshitz et al., 2001). For instance, Orasanu (2005) developed recommendations for training astronauts to be successful decision makers by evaluating what makes current astronauts successful, such as developing team cohesion and managing stress. Naturalistic decision making can be applied to a broad range of behaviors and environments. These applications can include individuals as diverse as soccer players, railroad controllers, or NASA astronauts (Farrington-Darby et al., 2006; Orasanu, 2005; Patel, Kaufman, & Arocha, 2002).

Group Decision Making

Groups form decisions differently than individuals. Often, there are benefits to making decisions in groups. A phenomenon called *groupthink*, however, can occur that seriously impairs the quality of decisions made. The next sections explore group decision making in more detail.

in the lab of **GERD GIGERENZER**

Making Decisions in an Uncertain World

In my lab, we investigate *bounded rationality*, that is, how humans make decisions in an *uncertain* world. In the real world, omniscience is absent and surprises can happen; nevertheless, people have to make decisions, such as whom to trust, what medication to take, or how to invest money.

The first question we pose is descriptive: What heuristics do people rely on to make decisions in an uncertain world? We have investigated a number of heuristics, including those relying on recognition (the recognition and fluency heuristics), one good reason (such as *take-the-best*), and on the wisdom of others (such as *imitate-the-majority)*. The study of the *adaptive toolbox* investigates the heuristics used, their building blocks, and the core cognitive capacities they exploit.

Gerd Gigerenzer

Photo by Dietmar Gust

Our second question asks: In what environment does a heuristic work or fail? To find answers, we develop formal models of heuristics, using analysis and computer simulation. We found that simple heuristics that rely on only one good reason (such as take-the-best) actually can make more accurate predictions than can complex strategies such as multiple regression or neural networks. This result shows that heuristics are not second best, and that less information, computation, and time can lead to better decisions. In fact, in an uncertain world, one needs to ignore part of the information to make good judgments.

We also use our research to design heuristics and environments that help people make better decisions. For instance, physicians in Michigan hospitals now use heuristics called *fast-and-frugal trees* when making intensive care unit allocations. These simple heuristics are fast and frugal, and yet are better than complex linear regression models at predicting heart attacks.

One aspect of intuitive design is risk communication. In a contraceptive pill scare in the UK, the media reported that third-generation pills increase the risk of potentially life-threatening blood clots (thrombosis) by 100%. Many women stopped taking the pill, resulting in unwanted pregnancies and an estimated 13,000 additional abortions. How big is 100%? Studies had shown that out of every 7,000 women who took the earlier second-generation pill, about 1 had a thrombosis; this number increased to 2 among women who took third-generation pills. That is, the *absolute risk increase* was only 1 in 7,000 while the *relative risk increase* was indeed 100%. Had the media reported the absolute risks, few women would have panicked. The pill scare illustrates how citizens' fears are manipulated by framing numbers in a misleading and nontransparent way. During the last few years, I have trained some 1,000 physicians and dozens of U.S. federal judges in understanding risks, for instance when evaluating cancer screening or DNA tests. Few physicians and lawyers have been educated in risk communication, and this blind spot is an important area in which psychologists can apply their knowledge and help.

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Benefits of Group Decisions

Working as a group can enhance the effectiveness of decision making, just as it can enhance the effectiveness of problem solving. Many companies combine individuals into teams to improve decision making. By forming decision-making teams, the group benefits from the expertise of each of the members. There is also an increase in resources and ideas (Salas, Burke, & Cannon Bowers, 2000). Another benefit of group decision making is improved group memory over individual memory (Hinsz, 1990). Groups that are successful in decision making exhibit a number of similar characteristics, including the following:

- the group is small
- it has open communication
- members share a common mind-set
- members identify with the group
- members agree on acceptable group behavior (Shelton, 2006)

In juries, members share more information during decision making when the group is made up of diverse members (Sommers, 2006) The juries are thereby in a position to make better decisions. Furthermore, in examining decision making in public policy groups, interpersonal influence is important (Jenson, 2007). Group members frequently employed tactics to affect other members' decisions (Jenson, 2007). The most frequently used and influential tactics were inspirational and rational appeals.

Groupthink

There can be disadvantages associated with group decision making, however. Of these disadvantages, one of the most explored is groupthink. *Groupthink* is a phenomenon characterized by premature decision making that is generally the result of group members attempting to avoid conflict (Janis, 1971). Groupthink frequently results in suboptimal decision making that avoids nontraditional ideas (Esser, 1998).

What conditions lead to groupthink? Janis (1971) cited three kinds:

1. an isolated, cohesive, and homogeneous group is empowered to make decisions;
2. objective and impartial leadership is absent, within the group or outside it; and
3. high levels of stress impinge on the group decision making process.

Another cause of groupthink is anxiety (Chapman, 2006). When group members are anxious, they are less likely to explore new options and will likely try to avoid further conflict.

The groups responsible for making foreign policy decisions are excellent candidates for groupthink. They are usually like-minded. Moreover, they frequently isolate themselves from what is going on outside their own group. They generally try to meet specific objectives and believe they cannot afford to be impartial. Also, of course, they are under very high stress because the stakes involved in their decisions can be tremendous.

But what exactly is groupthink? Janis (1971) delineated six symptoms of groupthink:

1. *Closed mindedness*—the group is not open to alternative ideas.
2. *Rationalization*—the group goes to great lengths to justify both the process and the product of its decision making, distorting reality where necessary in order to be persuasive.
3. *Squelching of dissent*—those who disagree with the group are ignored, criticized, or even ostracized.
4. *Formation of a "mindguard"* for the group—one person appoints himself or herself the keeper of the group norm and ensures that people stay in line.

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5. *Feeling invulnerable*—the group believes that it must be right, given the intelligence of its members and the information available to them.
6. *Feeling unanimous*—members believe that everyone unanimously shares the opinions expressed by the group.

Defective decision making results from groupthink, which in turn is due to examining alternatives insufficiently, examining risks inadequately, and seeking information about alternatives incompletely.

Consider how groupthink might arise in a decision when college students decide to damage a statue on the campus of a football rival to teach a lesson to the students and faculty in the rival university. The students rationalize that damage to a statue really is no big deal. Who cares about an old ugly statue anyway? When one group member dissents, other members quickly make him feel disloyal and cowardly. His dissent is squelched. The group's members feel invulnerable. They are going to damage the statue under the cover of darkness, and the statue is never guarded. They are sure they will not be caught. Finally, all the members agree on the course of action. This apparent feeling of unanimity convinces the group members that far from being out of line, they are doing what needs to be done.

Antidotes for Groupthink

Janis (1971) has prescribed several antidotes for groupthink. For example, the leader of a group should encourage constructive criticism, be impartial, and ensure that members seek input from people outside the group. The group should form subgroups that meet separately to consider alternative solutions to a single problem. It is important that the leader take responsibility for preventing spurious conformity to a group norm.

In 1997, members of the Heaven's Gate cult in California committed mass suicide in the hope of meeting up with extraterrestrials in a spaceship trailing the Hale-Bopp comet. Although this group suicide is a striking example of conformity to a destructive group norm, similar events have occurred throughout human history, such as the suicide of more than 900 members of the Jonestown, Guyana, religious cult in 1978. In 2010, a series of incredibly bad decisions by a group of oilrig operators on the Deepwater Horizon, situated in the Gulf of Mexico, led to the largest oil well leak in history. And even in the 21st century, suicide bombers are killing themselves and others in carefully planned attacks.

Neuroscience of Decision Making

As in problem solving, the prefrontal cortex, and particularly the anterior cingulate cortex, is active during the decision-making process (Barraclough, Conroy, & Lee, 2004; Kennerley et al., 2006; Rogers et al., 2004). Explorations of decision making in monkeys have noted activation in the parietal regions of the brain (Platt & Glimcher, 1999). The amount of gain associated with a decision also affects the amount of activation observed in the parietal region (Platt & Glimcher, 1999).

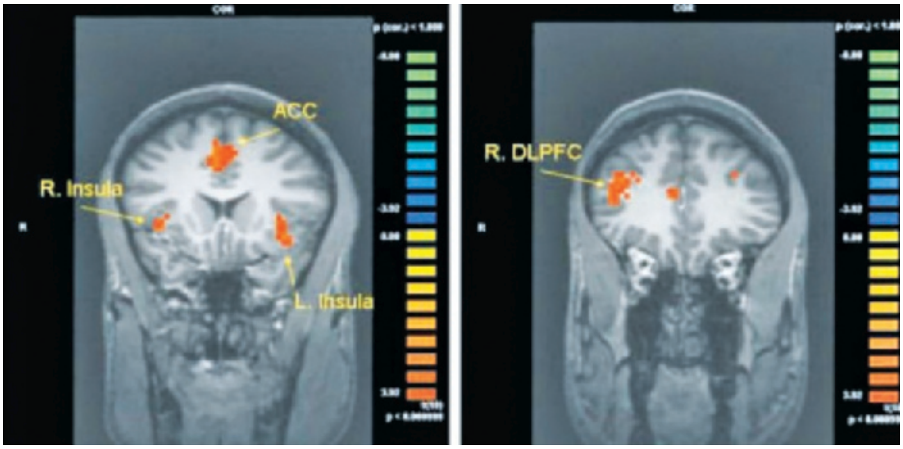
The ultimatum game is one neuroscientists frequently use to study decision making. One player (the proposer) makes an offer to the second player (the responder) on how to split a certain amount of money, say $10. The responder then can either accept the offer, in which case each player receives the amount of money suggested by the proposer, or reject the offer, in which case neither of the two players receives any money. Classical decision theory suggests that the responder should accept any offer because getting less money is still better than getting no money at all. This is not the way people typically react, however, because emotions play a role in their decisions.

When people get an offer that splits the money in an unfair way (e.g., $2 for the responder and $8 for the proposer), responders often reject the offer, thus ending up with no money. This response is likely due to people's dissatisfaction with their feeling that they have been treated unfairly or even cheated (Pillutla & Murnighan, 1996). Studies employing fMRI technology while players are engaged in the ultimatum game have found that the anterior insula is involved when people are confronted with unfair offers from others. One study (Corradi-Dell'Acqua et al., 2013) had responders make decisions on offers either for themselves or on behalf of a third person. The decisions on behalf of someone else were expected to reduce the negative emotions that are aroused when a person feels he or she is being treated unfairly. And, in fact, although the anterior insula was activated no matter whether the unfair offer was presented to the responder or to a third person, the middle anterior portion of the medial prefrontal cortex was activated only when the unfair offer was directed at the responder him- or herself. At the same time, the prefrontal cortex is activated in such tasks no matter whether the responder accepts or rejects offers, which indicates that the prefrontal cortex is involved on a more general basis in making decisions (Sanfey et al., 2003; see Figure 12.2 ■).

Examination of decision making in drug abusers identified a number of areas involved in risky decisions. The researchers studied drug abusers because drug abuse, by its very nature, produces risky decisions. They found decreased activation in the left pregenual anterior cingulate cortex of drug abusers (Fishbein et al., 2005). These findings suggest that during decision making, the anterior cingulate cortex is involved in the consideration of potential rewards.

Another study had healthy participants play the gambling game Blackjack. The researchers found that suboptimal decisions (too risky or too cautious) were associated with increased activity in the anterior cingulate cortex (Hewig et al., 2008).

Another interesting effect seen in this area is observed in participants who have difficulty with a decision. In one study, participants made decisions concerning whether an item was old or new and which of two items was larger (Fleck et al., 2006). Decisions that were rated lowest in confidence and that took the most time to answer were associated with higher activation of the anterior cingulate cortex.



(a) (b)

Sanfey AG1, Rilling JK, Aronson JA, Nystrom LE, Cohen JD.

■ **Figure 12.2 Activation Related to Presentation of an Unfair Offer.** (a) Map of the *t* statistic for the contrast (unfair human offer–fair human offer) showing activation of bilateral anterior insula and anterior cingulate cortex. Areas in orange showed greater activation following unfair as compared with fair offers ($P < 0.001$). (b) Map of the *t* statistic for the contrast (unfair human offer–fair human offer) showing activation of right dorsolateral prefrontal cortex.

These findings suggest that this area of the brain is involved in the comparison and weighing of possible solutions.

CONCEPT CHECK

1. Why can the model of the economic man and woman not explain human decision making satisfactorily?
2. Why do we use heuristics?
3. What is the difference between overconfidence and hindsight bias?
4. Name and describe three fallacies.
5. What are the symptoms of groupthink?
6. Which parts of the brain play prominent roles in decision making?

Deductive Reasoning

In judgment and decision making, we evaluate opportunities and select one choice over another. A related kind of thinking is reasoning. **Reasoning** is the process of drawing conclusions from principles and from evidence (Leighton & Sternberg, 2004; Sternberg, 2004; Wason & Johnson-Laird, 1972). In reasoning, we move from what is already known to infer a new conclusion or to evaluate a proposed conclusion.

Reasoning is often divided into two types: deductive and inductive reasoning.

What Is Deductive Reasoning?

Deductive reasoning is the process of reasoning from one or more general statements regarding what is known to reach a logically certain conclusion (Johnson-Laird, 2000; Rips, 1999; Williams, 2000). It often involves reasoning from one or more general statements regarding what is known to a specific application of the general statement.

Deductive reasoning is based on logical propositions. A **proposition** is basically an assertion, which may be either true or false. Examples are "Cognitive psychology students are brilliant," "Cognitive psychology students wear shoes," or "Cognitive psychology students like peanut butter." In a logical argument, **premises** are propositions about which arguments are made. Cognitive psychologists are interested particularly in propositions that may be connected in ways that require people to draw reasoned conclusions. That is, deductive reasoning is useful because it helps people connect various propositions to draw conclusions. Cognitive psychologists want to know how people connect propositions to draw conclusions. Some of these conclusions are well reasoned; others are not.

Much of the difficulty of reasoning is in even understanding the language of problems (Girotto, 2004). Some of the mental processes used in language understanding and the cerebral functioning underlying them are used in reasoning, too (Lawson, 2004).

Conditional Reasoning

One type of deductive reasoning is conditional reasoning. In the next sections, we will explore what conditional reasoning is and how it works.

What Is Conditional Reasoning?

One of the primary types of deductive reasoning is **conditional reasoning**, in which the reasoner must draw a conclusion based on an *if-then* proposition. The conditional if-then proposition states that if antecedent condition *p* is met, then consequent event *q* follows. For example, "If students study hard, then they score high on their exams." Under some circumstances, if you have established a conditional proposition, then you may draw a well-reasoned conclusion. The usual set of conditional propositions from which you can draw a well-reasoned conclusion is, "If *p*, then *q*. *p*. Therefore, *q*." This inference illustrates deductive validity. That is, it follows logically from the propositions on which it is based. The following is also logical:

> "If students eat pizza, then they score high on their exams. They eat pizza. Therefore, they score high on their exams."

As you may have guessed, deductive validity does not equate with truth. You can reach deductively valid conclusions that are completely untrue with respect to the world. Whether the conclusion is true depends on the truthfulness of the premises. In fact, people are more likely to mistakenly accept an illogical argument as logical if the conclusion is factually true. For now, however, we put aside the issue of truth and focus only on the **deductive validity**, or logical soundness, of the reasoning. One set of propositions and its conclusion is the following argument:

> "If *p*, then *q*. *p*. Therefore, *q*."

which is termed a *modus ponens* argument. In the *modus ponens* argument, the reasoner affirms the antecedent (*p*). For example, take the argument "If you are a husband, then you are married. Harrison is a husband. Therefore, he is married." The set of propositions for the *modus ponens* argument is shown in Table 12.2 ■.

In addition to the *modus ponens* argument, you may draw another well-reasoned conclusion from a conditional proposition, given a different second proposition:

> "If *p*, then *q*. Not *q*. Therefore, not *p*."

Table 12.2 Conditional Reasoning: Deductively Valid Inferences and Deductive Fallacies

Two kinds of conditional propositions lead to valid deductions, and two others lead to deductive fallacies; *p* is called the *antecedent*; *q* is called the *consequent*. → stands for then, and ∴ stands for therefore.

Type of Argument		Conditional Proposition	Existing Condition	Inference
Deductively valid inferences	*Modus ponens*—*Affirming the antecedent*	$p \rightarrow q$ If you are a mother, then you have a child.	p You are a mother.	$\therefore q$ Therefore, you have a child.
	Modus tollens—*Denying the consequent*	$p \rightarrow q$ If you are a mother, then you have a child.	$\neg q$ You do not have a child.	$\therefore \neg p$ Therefore, you are not a mother.
Deductive fallacies	*Denying the antecedent*	$p \rightarrow q$ If you are a mother, then you have a child.	$\neg p$ You are not a mother.	$\therefore \neg q$ Therefore, you do not have a child.
	Affirming the consequent	$p \rightarrow q$ If you are a mother, then you have a child.	q You have a child.	$\therefore p$ Therefore, you are a mother.

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This inference is also deductively valid. This particular set of propositions and its conclusion is termed a *modus tollens* argument, in which the reasoner denies the consequent. For example, we modify the second proposition of the argument to deny the consequent:

> "If you are a husband, then you are married. Harrison is not married. Therefore, he is not a husband."

Table 12.2 shows two conditions in which a well-reasoned conclusion can be reached. It also shows two conditions in which such a conclusion cannot be reached. As the examples illustrate, some inferences based on conditional reasoning are fallacies, which lead to conclusions that are not deductively valid. When using conditional propositions, we cannot reach a deductively valid conclusion based either on denying the antecedent condition or on affirming the consequent. Let's return to the proposition, "If you are a husband, then you are married." We would not be able to confirm or to refute the proposition based on denying the antecedent: "Joan is not a husband. Therefore, she is not married." Even if we ascertain that Joan is not a husband, we cannot conclude that she is not married. Similarly, we cannot deduce a valid conclusion by affirming the consequent: "Joan is married. Therefore, she is a husband." Even if Joan is married, her spouse may not consider her a husband.

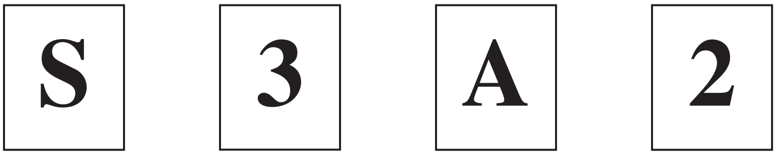
The Wason Selection Task

Conditional reasoning can be studied in the laboratory using a "selection task" (Wason, 1968, 1969, 1983; Wason & Johnson-Laird, 1970, 1972). Participants are presented with a set of four two-sided cards. Each card has a number on one side and a letter on the other side. Face up are two letters and two numbers. The letters are a consonant and a vowel. The numbers are an even number and an odd number. For example, participants might be presented with the set of cards shown in Figure 12.3 ■.

Each participant then is told a conditional statement. For example, "If a card has a consonant on one side, then it has an even number on the other side." The task is to determine whether the conditional statement is true or false. One does so by turning over the exact number of cards necessary to test the conditional statement. That is, the participant must not turn over any cards that are not valid tests of the statement. But the participant must turn over all cards that are valid tests of the conditional proposition. Which cards would you turn?

Table 12.3 ■ illustrates the four possible tests participants might perform on the cards. Two of the tests (*modus ponens:* affirming the antecedent, and *modus tollens:* denying the consequent) are both necessary and sufficient for testing the conditional statement:

- That is, to evaluate the deduction, the participant must turn over the card showing a consonant to see whether it has an even number on the other side. He or she thereby affirms the antecedent (the *modus ponens* argument).



■ **Figure 12.3 Selection Task.** Which two cards would you turn to confirm the rule, "If a card has a consonant on one side, then it has an even number on the other side"?

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Table 12.3 Conditional Reasoning: Wason Selection Task

In the Wason selection task, Peter Wason presented participants with a set of four cards, from which the participants were to test the validity of a given proposition. This table illustrates how a reasoner might test the conditional proposition ($p \rightarrow q$), "If a card has a consonant on one side (p), then it has an even number on the other side (q)."

Proposition Based on What Shows on the Face of the Card	Test	Type of Reasoning	
p A given card has a consonant on one side (e.g., "S," "F," "V," or "P").	**∴ *q*** Does the card have an even number on the other side?	Based on *modus ponens*	Deductively valid inferences
¬ *q* A given card does not have an even number on one side. That is, a given card has an odd number on one side (e.g., "3," "5," "7," or "9").	**∴ ¬ *p*** Does the card not have a consonant on the other side? That is, does the card have a vowel on the other side?	Based on *modus tollens*	
¬ *p* A given card does not have a consonant on one side. That is, a given card has a vowel on one side (e.g., "A," "E," "I," or "O").	**∴ ¬ *q*** Does the card not have an even number on the other side? That is, does the card have an odd number on the other side?	Based on denying the antecedent	Deductive fallacies
q A given card has an even number on one side (e.g., "2," "4," "6," or "8").	**∴ *p*** Does the card have a consonant on the other side?	Based on affirming the consequent	

- In addition, the participant must turn over the card showing an odd number (i.e., not an even number) to see whether it has a vowel (i.e., not a consonant) on the other side. He or she thereby denies the consequent (the *modus tollens* argument).

The other two possible tests (denying the antecedent and affirming the consequent) are irrelevant. That is, the participant need not turn over the card showing a vowel (i.e., not a consonant). To do so would be to deny the antecedent. He or she also need not turn over the card showing an even number (i.e., not a odd number). To do so would be to affirm the consequent.

Most participants knew to test for the *modus ponens* argument. Many participants, however, failed to test for the *modus tollens* argument. Some of these participants instead tried to deny the antecedent as a means of testing the conditional proposition. ■ To try a typical experiment using Wason Selection, go to Lab 53, Wason Selection Task, in CogLab.

Conditional Reasoning in Everyday Life

Most people of all ages (at least starting in elementary school) appear to have little difficulty in recognizing and applying the *modus ponens* argument. However, few people spontaneously recognize the need for reasoning by means of the *modus tollens* argument. Many people do not recognize the logical fallacies of denying the antecedent or affirming the consequent, at least as these fallacies are applied to abstract reasoning problems (Braine & O'Brien, 1991; O'Brien, 2004; Rips, 1988, 1994). In fact, some evidence suggests that even people who have taken a course in logic fail to demonstrate deductive reasoning across various situations (Cheng et al., 1986). Even training aimed directly at improving reasoning leads to mixed results. After training aimed at increasing reasoning, people experience a significant increase in the use of mental models and rules. However, after this training, people may experience only a moderate increase in the use of deductive reasoning (Leighton, 2006).

Why might both children and adults fallaciously affirm the consequent or deny the antecedent? Perhaps they do so because of invited inferences that follow from normal discourse comprehension of conditional phrasing (Rumain, Connell, & Braine, 1983). For instance, suppose that a textbook publisher advertises,

> "If you buy the *Introduction to Ethics* textbook, then we will give you a $5 rebate."

You probably correctly infer that if you do not buy this textbook, the publisher will not give you a $5 rebate. Formal deductive reasoning, however, would consider this denial of the antecedent to be fallacious. The statement says nothing about what happens if you do *not* buy the textbook. Similarly, you may infer that you must have bought this textbook (affirm the consequent) if you received a $5 rebate from the publisher. But the statement says nothing about the range of circumstances that lead you to receive the $5 rebate. There may be other ways to receive it. Both inferences are fallacious according to formal deductive reasoning, but both are quite reasonably invited inferences in everyday situations. It helps when the wording of conditional reasoning problems either explicitly or implicitly disinvites these inferences. People are then much less likely to engage in these logical fallacies.

The demonstration of conditional reasoning also is influenced by the presence of contextual information that converts the problem from one of abstract deductive reasoning to one that applies to an everyday situation. For example, participants received both the Wason Selection Task and a modified version of the Wason Selection Task (Griggs & Cox, 1982). In the modified version, the participants were asked to suppose that they were police officers. As officers, they were attempting to enforce the laws applying to the legal age for drinking alcoholic beverages. The particular rule to be enforced was as follows:

> "If a person is drinking beer, then the person must be over 19 years of age."

Each participant was presented with a set of four cards:

1. drinking a beer
2. drinking a Coke
3. 16 years of age
4. 22 years of age

The participant then was instructed to "Select the card or cards that you definitely need to turn over to determine whether or not the people are violating the rule" (Griggs & Cox, 1982, p. 414). On the one hand, none of Griggs and Cox's participants had responded correctly on the abstract version of the Wason Selection Task. On the other hand, a remarkable 72% of the participants correctly responded to the modified version of the task—that is, they turned cards 1 and 3.

People with dispositions higher in distrust toward others or who have been exposed to a face that elicits distrust before working on the Wason selection task engage more frequently in negative hypothesis testing (testing for *modus tollens*) and thus more often arrived at the right conclusions. Feeling distrust may make us less likely to take the correctness of any information for granted and thus to look harder to verify the information we receive (Mayo, Alfasi, & Schwarz, 2014).

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Influences on Conditional Reasoning

A more recent modification of the task based on drinking and age has shown that beliefs regarding plausibility influence whether people choose the *modus tollens* argument (denying the consequent—checking to see whether a person who is younger than 19 years of age is not drinking beer). When the test involves checking to see whether an 18-year-old is drinking beer, people are far more likely to try the *modus tollens* argument than when they have to check whether a 4-year-old is drinking beer. Nevertheless, the logical argument is the same in both cases (Kirby, 1994).

How do people use deductive reasoning in realistic situations? Two investigators have suggested that, rather than using formal inference rules, people often use pragmatic reasoning schemas (Cheng & Holyoak, 1985, 2008). **Pragmatic reasoning schemas** are general organizing principles or rules related to particular kinds of goals, such as permissions, obligations, or causations. These schemas sometimes are referred to as *pragmatic rules.* These pragmatic rules are not as abstract as formal logical rules. Yet, they are sufficiently general and broad so that they can apply to a wide variety of specific situations. Prior beliefs, in other words, matter in reasoning (Evans & Feeney, 2004).

Alternatively, one's performance may be affected by *perspective effects*—that is, whether one takes the point of view of the police officers or of the people drinking the alcoholic beverages (Almor & Sloman, 1996; Staller, Sloman, & BenZeev, 2000). So it may not be permissions *per se* that matter. Rather, what may matter are the perspectives one takes when solving such problems.

Thus, consider situations in which our previous experiences or our existing knowledge cannot tell us all we want to know. Pragmatic reasoning schemas help us deduce what might reasonably be true. Particular situations or contexts activate particular schemas. For example, suppose that you are walking across campus and see someone who looks extremely young. Then you see the person walk to a car. He unlocks it, gets in, and drives away. This observation would activate your permission schema for driving: "If you are to be permitted to drive alone, then you must be at least 16 years old." You might now deduce that the person you saw is at least 16 years old. In one experiment, 62% of participants correctly chose *modus ponens* and *modus tollens* arguments when the conditional reasoning task was presented in the context of permission statements. Only 11% did so when the task was presented in the context of arbitrary statements unrelated to pragmatic reasoning schemas (Cheng & Holyoak, 1985).

Researchers conducted an extensive analysis comparing the standard abstract Wason selection task with an abstract form of a permission problem (Griggs & Cox, 1993). The standard abstract form might be "If a card has an 'A' on one side, then it must have a '4' on the other side." The abstract permission form might be, "If one is to take action 'A', then one must first satisfy precondition 'P'." Performance on the abstract permission task was still superior (49% correct overall) to performance on the standard abstract task (only 9% correct overall; Griggs & Cox, 1993; Manktelow & Over, 1990, 1992).

Evolution and Reasoning

A different approach to conditional reasoning takes an evolutionary view of cognition (Cummins, 2004). This view asks what kinds of thinking skills would provide a naturally selective advantage for humans in adapting to our environment across evolutionary time (Cosmides, 1989; Cosmides & Tooby, 1996). To gain insight into human cognition, we should look to see what kinds of adaptations would have been most useful in the distant past. So we hypothesize on how human hunters and gatherers would have thought during the millions of years of evolutionary time that predated the relatively recent development of agriculture and the very recent development of industrial societies.

How has evolution influenced human cognition? Humans may possess something like a schema acquisition device (Cosmides, 1989). It facilitates our ability to quickly glean important information from our experiences. It also helps us to organize that information into meaningful frameworks. In Cosmides's view, these schemas are highly flexible. But they also are specialized for selecting and organizing the information that will most effectively aid us in adapting to the situations we face. One of the distinctive adaptations shown by human hunters and gatherers has been in the area of social exchange. There are two kinds of inferences in particular that social exchange schemas facilitate: inferences related to cost–benefit relationships and inferences that help people detect when someone is cheating in a particular social exchange. In earlier times, working together may well have been even more important than it is today. Imagine one partner taking care of the children while the other partner goes out to hunt. When the hunter returns home, he shares the meat with the rest of the family in exchange for his partner having taken care of the offspring. Similarly, detecting a cheater who does not comply with rules may have made the difference between life and death.

Syllogistic Reasoning: Categorical Syllogisms

In addition to conditional reasoning, the other key type of deductive reasoning is syllogistic reasoning, which is based on the use of syllogisms. **Syllogisms** are deductive arguments that involve drawing conclusions from two premises (Maxwell, 2005; Rips, 1994, 1999). All syllogisms comprise two premises and a conclusion. Unfortunately, sometimes, the conclusion may be that no logical conclusion may be reached based on the two given premises.

What Are Categorical Syllogisms?

Probably the most well-known kind of syllogism is the categorical syllogism. Like other kinds of syllogisms, categorical syllogisms comprise two premises and a conclusion. In the case of the **categorical syllogism**, the premises state something about the category memberships of the terms. In fact, each term represents all, none, or some of the members of a particular class or category. As with other syllogisms, each premise contains two terms. One of them must be the middle term, common to both premises. The first and the second terms in each premise are linked through the categorical membership of the terms. That is, one term is a member of the class indicated by the other term. However the premises are worded, they state that some (or all or none) of the members of the category of the first term are (or are not) members of the category of the second term. To determine whether the conclusion follows logically from the premises, the reasoner must determine the category memberships of the terms. An example of a categorical syllogism follows:

Premise 1: All cognitive psychologists are pianists.
Premise 2: All pianists are athletes.
Conclusion: Therefore, all cognitive psychologists are athletes.

Logicians often use circle diagrams to illustrate class membership. They make it easier to figure out whether a particular conclusion is logically sound. The conclusion for this syllogism does in fact follow logically from the premises. This is shown in the circle diagram in Figure 12.4 ■. The conclusion is false, however, because the premises are false. For the preceding categorical syllogism, the *subject* is cognitive psychologists, the *middle term* is pianists, and the *predicate* is athletes. In both premises, we asserted that all members of the category of the first term were members of the category of the second term.

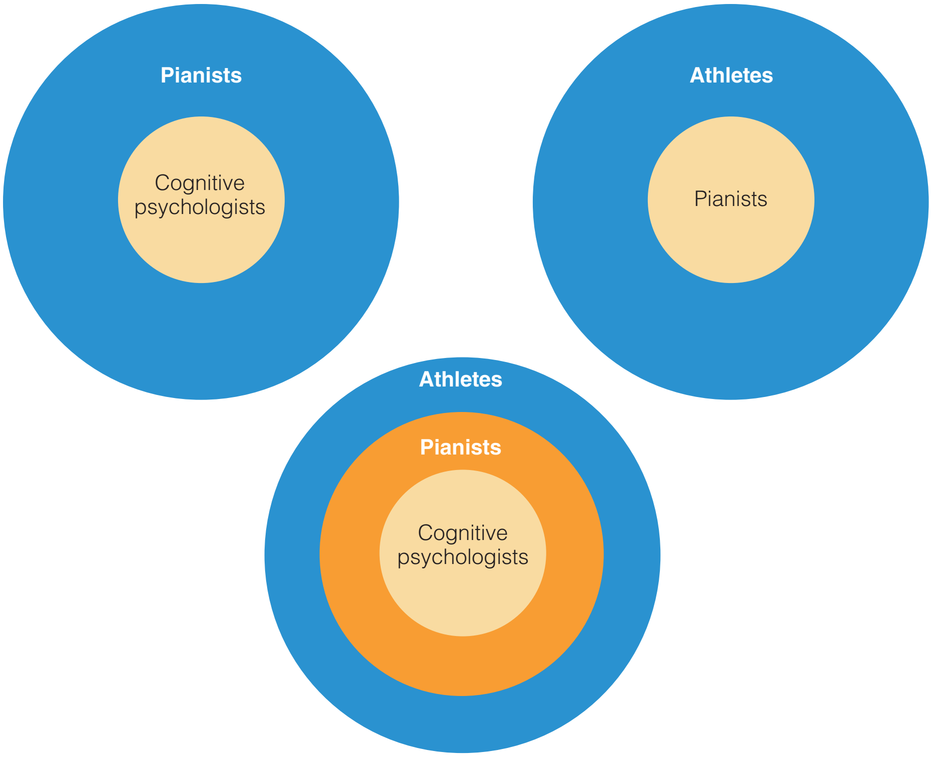


Figure 12.4 Circle Diagrams Representing a Categorical Syllogism. Circle diagrams may be used to represent categorical syllogisms such as the one shown here: "All cognitive psychologists are pianists. All pianists are athletes. Therefore, all cognitive psychologists are athletes." It follows from the syllogism that all cognitive psychologists are athletes. If, however, the premises are not true, then a deduction that is logically valid still is not necessarily true, as is the case in this example.

Source: Based on *In Search of the Human Mind*, by Robert J. Sternberg. Copyright © 1995 by Harcourt Brace & Company.

There are four kinds of premises:

1. *Universal affirmative statements*: Statements of the form "All A are B" because they make a positive (affirmative) statement about all members of a class (universal).
2. *Universal negative statements:* negative statements about all members of a class (e.g., "No cognitive psychologists are flutists.").
3. *Particular affirmative statements:* positive statements about some members of a class (e.g., "Some cognitive psychologists are left handed.").
4. *Particular negative statements:* negative statements about some members of a class (e.g., "Some cognitive psychologists are not physicists.")

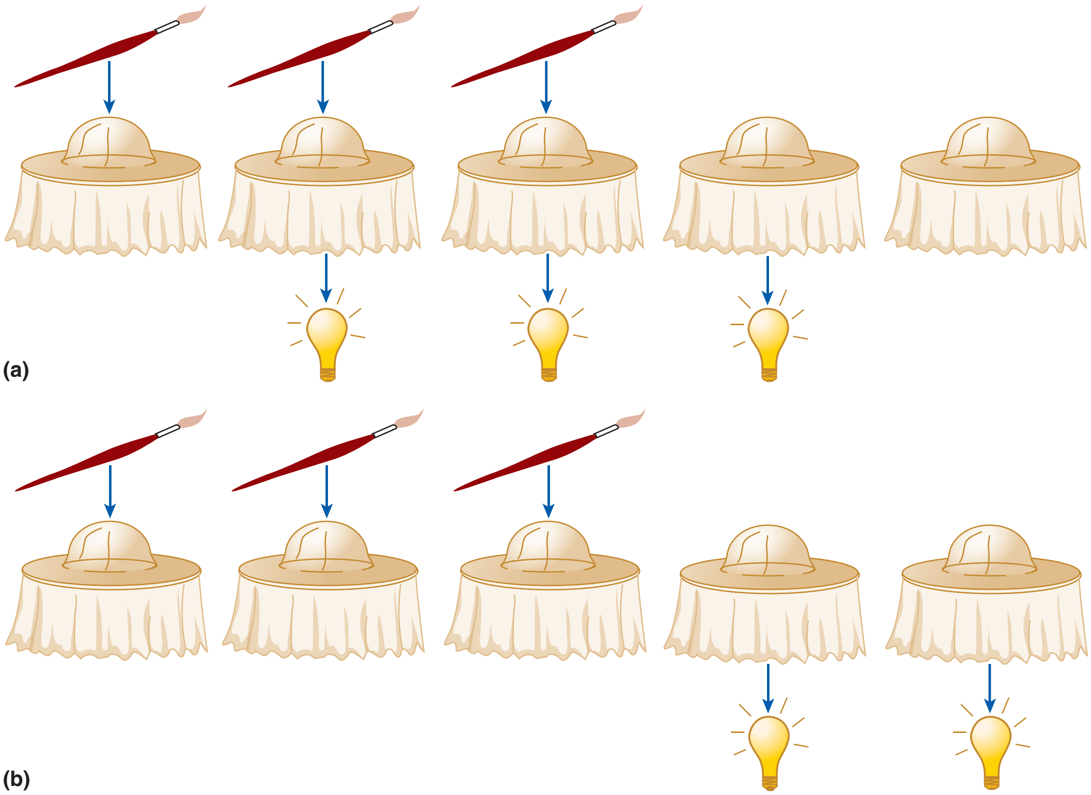
In all kinds of syllogisms, some combinations of premises lead to no logically valid conclusion. In categorical syllogisms, in particular, we cannot draw logically valid conclusions from categorical syllogisms with two particular premises or with two negative premises. For example, "Some cognitive psychologists are left handed. Some left handed people are smart." On the basis of these premises, you cannot conclude even that some cognitive psychologists are smart. The left-handed people who are smart might not be the same left-handed people who are cognitive psychologists. We just don't know. Consider a negative example: "No students are stupid. No stupid people eat pizza." We cannot conclude anything one way or the other about whether students eat pizza based on these two negative premises. As you may have guessed, people appear to have more difficulty (work more slowly and make more errors) when trying to deduce conclusions based on one or more particular premise or negative premise.

How Do People Solve Syllogisms?

People may solve syllogisms by using a semantic (meaning based) process based on mental models (Ball & Quayle, 2009; Espino et al., 2005; Johnson-Laird & Savary, 1999; Johnson-Laird & Steedman, 1978). This view of reasoning as involving semantic processes based on mental models may be contrasted with rule-based ("syntactic") processes, such as those characterized by formal logic. A **mental model** is an internal representation of information that corresponds analogously with whatever is being represented (see Johnson-Laird, 1983). Some mental models are more likely to lead to a deductively valid conclusion than are others. In particular, some mental models may not be effective in disconfirming an invalid conclusion.

For example, in the Johnson-Laird study, participants were asked to describe their conclusions and their mental models for the syllogism, "All of the artists are beekeepers. Some of the beekeepers are clever. Are all artists clever?" One participant said, "I thought of all the little . . . artists in the room and imagined they all had beekeeper's hats on" (Johnson-Laird & Steedman, 1978, p. 77). Figure 12.5 ■ shows two different mental models for this syllogism. As the figure shows, the choice of a mental model may affect the reasoner's ability to reach a valid deductive conclusion. Because some models are better than others for solving some syllogisms, a person is more likely to reach a deductively valid conclusion by using more than one mental model. In the figure, the mental model shown in Figure 12.5(a) may lead to the deductively invalid conclusion that some artists are clever. By observing the alternative model in Figure 12.5(b), we can see an alternative view of the syllogism. It shows that the conclusion that some artists are clever may not be deduced on the basis of this information alone. Specifically, perhaps the beekeepers who are clever are not the same as the beekeepers who are artists.

As mentioned previously, circle diagrams are often used to represent categorical syllogisms. In circle diagrams, you can use overlapping, concentric, or nonoverlapping



■ **Figure 12.5 Mental Models Representing a Syllogism.** Philip Johnson-Laird and Mark Steedman hypothesized that people use various mental models analogously to represent the items within a syllogism. Some mental models are more effective than others, and for a valid deductive conclusion to be reached, more than one model may be necessary, as shown here. (See text for explanation.)

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circles to represent the members of different categories (see Figure 12.4). People can learn how to improve their reasoning by being taught how to draw circle diagrams (Nickerson, 2004). Amazingly, even congenitally blind people are able to create spatial mental models to assist them in their reasoning processes (Fleming et al., 2006; Knauff & May, 2006).

The difficulty of many problems of deductive reasoning relates to the number of mental models needed to adequately represent the premises of the deductive argument (Johnson-Laird, Byrne, & Schaeken, 1992). Arguments that entail only one mental model may be solved quickly and accurately. However, to infer accurate conclusions based on arguments that may be represented by multiple alternative models is much harder. Such inferences place great demands on working memory (Gilhooly, 2004). In these cases, the individual must simultaneously hold in working memory each of the various models. Only in this way can he or she reach or evaluate a conclusion. Thus, limitations of working memory capacity may underlie at least some of the errors observed in human deductive reasoning (Johnson-Laird, Byrne, & Schaeken, 1992).

Aids and Obstacles to Deductive Reasoning

In deductive reasoning, as in many other cognitive processes, we engage in many heuristic shortcuts. These shortcuts sometimes lead to inaccurate conclusions. In addition to these shortcuts, we often are influenced by biases that distort the outcomes of our reasoning. In this section, we examine heuristics and biases in deductive reasoning. Finally, we look at ways to enhance deductive reasoning skills.

Heuristics in Deductive Reasoning

Heuristics in syllogistic reasoning include *overextension errors*. In these errors, we overextend the use of strategies that work in some syllogisms to syllogisms in which the strategies fail us. For example, although reversals work well with universal negatives, they do not work with other kinds of premises. We also experience *foreclosure effects* when we fail to consider all the possibilities before reaching a conclusion. In addition, *premise-phrasing effects* may influence our deductive reasoning, for example, the sequence of terms or the use of particular qualifiers or negative phrasing. Premise-phrasing effects may lead us to leap to a conclusion without adequately reflecting on the deductive validity of the syllogism.

Biases in Deductive Reasoning

Biases that affect deductive reasoning generally relate to the content of the premises and the believability of the conclusion. They also reflect the tendency toward **confirmation bias**. In confirmation bias, we seek confirmation rather than disconfirmation, or rejection, of what we already believe. Suppose the content of the premises and a conclusion both seem to be true. In such cases, reasoners tend to believe in the validity of the conclusion, even when the logic is flawed (Evans, Barston, & Pollard, 1983).

Confirmation bias can be detrimental and even dangerous in some circumstances. For instance, in an emergency room, if a doctor assumes that a patient has condition X, the doctor may interpret the set of symptoms as supporting the diagnosis without fully considering all alternative interpretations (Pines, 2005). This shortcut can result in inappropriate diagnosis and treatment, which can be extremely dangerous. Other circumstances where the effects of confirmation bias can be observed are in police investigations, paranormal beliefs, and stereotyping behavior (Ask & Granhag, 2005; Biernat & Ma, 2005; Lawrence & Peters, 2004). To a lesser extent, people also show the opposite tendency to disconfirm the validity of the conclusion when the conclusion or the content of the premises contradicts the reasoner's existing beliefs (Evans, Barston, & Pollard, 1983; Janis & Frick, 1943).

practical applications of COGNITIVE PSYCHOLOGY

Improving Your Deductive Reasoning Skills

Even without training, you can improve your own deductive reasoning by developing strategies to avoid making errors. For example, an unscrupulous politician might state that, "We know that some suspicious looking people are illegal aliens. We also know that some illegal aliens are terrorists. Therefore, we can be sure that some of those people whom we think are suspicious are terrorists and that they are out to destroy our country!" The politician's syllogistic reasoning is wrong. If some A are B and some B are C, it is not necessarily the case that any A are C. This is obvious when you realize that some men are happy people and some happy people are women, but this does not imply that some men are women.

Make sure you are using the proper strategies to solve syllogisms. Remember that reversals only work with universal negatives. Sometimes translating abstract terms to concrete ones (e.g., the letter *C* to cows) can help. Also, take the time to consider contrary examples and create more mental models. The more mental models you use for a given set of premises, the more confident you can be that if your conclusion is not valid, it will be disconfirmed. Thus, the use of multiple mental models increases the likelihood of avoiding errors. The use of multiple mental models also helps you to avoid the tendency to engage in confirmation bias. Circle diagrams also can be helpful in solving deductive reasoning problems.

Is the use of fingerprints in solving a crime an example of deductive reasoning? Why or why not?

CONCEPT CHECK

1. Which are deductively valid inferences in conditional reasoning?
2. What are categorical syllogisms?
3. How can mental models be helpful when solving categorical syllogisms?
4. What does "reversibility" mean with respect to premises?
5. Name some biases that we are prone to in deductive reasoning

Inductive Reasoning

We now consider inductive reasoning in more detail. First, we discuss what inductive reasoning is. Next, we will explore how we make causal inferences. Last, we will consider categorical inferences and reasoning by analogies.

What Is Inductive Reasoning?

Inductive reasoning is the process of reasoning from specific facts or observations to reach a likely conclusion that may explain the facts. The inductive reasoner then may use that probable conclusion to attempt to predict future specific instances (Johnson-Laird, 2000). The key feature distinguishing inductive from deductive reasoning is that, in inductive reasoning, we never can reach a logically certain conclusion. We only can reach a particularly well-founded or probable conclusion. With deductive reasoning, in contrast, reaching logically certain—deductively valid—conclusions is possible.

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For example, suppose that you notice that all the people enrolled in your cognitive psychology course are on the dean's list (or honor roll). From these observations, you could reason inductively that all students who enroll in cognitive psychology are excellent students (or at least earn the grades to give that impression). Unless, however, you can observe the grade point averages of all people who ever have taken or ever will take cognitive psychology, you will not be able to prove your conclusion. Furthermore, a single poor student who happened to enroll in a cognitive psychology course would disprove your conclusion. Still, after large numbers of observations, you might conclude that you had made enough observations to reason inductively.

Inductive reasoning forms the basis of the empirical method (Holyoak & Nisbett, 1998). In it, we cannot logically leap from saying, "All observed instances to date of *X* are *Y*" to saying, "Therefore, all *X* are *Y*." It is always possible that the next observed *X* will not be a *Y*. For example, you may say that all swans that you have ever seen are white. You cannot, however, then form the conclusion that all swans are white because the next swan you happen upon might be black. Indeed, black swans do exist.

In research, when we reject the null hypothesis (the hypothesis of no difference), we use inductive reasoning. We never know for sure whether we are correct in rejecting a null hypothesis.

According to cognitive psychologists, people use inductive reasoning for two reasons. First, it helps increase their ability to make sense out of the great variability in their environment. Second, it also helps them to predict events in their environment, thereby reducing their uncertainty. Thus, cognitive psychologists seek to understand the *how* rather than the *why* of inductive reasoning. We may (or may not) have some innate schema acquisition device. But we certainly are not born with all the inferences we manage to induce.

We already have implied that inductive reasoning often involves the processes of generating and testing hypotheses. In addition, we reach inferences by generalizing some broad understandings from a set of specific instances. As we observe additional instances, we further broaden our understanding. Or, we may infer specialized exceptions to the general understandings. For example, after observing quite a few birds, we may infer that birds can fly. But after observing penguins and ostriches, we may add to our generalized knowledge specialized exceptions for flightless birds.

Causal Inferences

One approach to studying inductive reasoning is to examine **causal inferences**—how people make judgments about whether something causes something else (Cheng, 1997, 1999; Spellman, 1997). The philosopher David Hume observed that we are most likely to infer causality when we observe covariation over time: First one thing happens, then another. If we see the two events paired enough, we may come to believe that the first causes the second.

Perhaps our greatest failing is one that extends to psychologists, other scientists, and nonscientists: We demonstrate confirmation bias, which may lead us to errors such as illusory correlations (Chapman & Chapman, 1967, 1969, 1975). Furthermore, we frequently make mistakes when attempting to determine causality based on correlational evidence alone. Correlational evidence cannot indicate the direction of causation. Suppose we observe a correlation between Factor A and Factor B. We may find one of three things:

1. It may be that Factor A causes Factor B.
2. It may be that Factor B causes Factor A.
3. Some higher order, Factor C, may cause both Factors A and B to occur together.

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On the basis of the correlational data, we cannot determine which of the three options indeed causes the observed phenomenon.

A related error occurs when we fail to recognize that many phenomena have multiple causes. For example, a car accident often involves several causes. It may have originated with the negligence of several drivers, rather than just one. Once we have identified one of the suspected causes of a phenomenon, we may commit what is known as a *discounting error.* We stop searching for additional alternative or contributing causes.

Confirmation bias can have a major effect on our everyday lives. For example, we may meet someone, expecting not to like her. As a result, we may treat her in ways that are different from how we would treat her if we expected to like her. She then may respond to us in less favorable ways. She thereby "confirms" our original belief that she is not likable. Confirmation bias thereby can play a major role in schooling. Teachers often expect little of students when they think them low in ability. The students then give the teachers little. The teachers' original beliefs are thereby "confirmed" (Sternberg, 1997). This effect is referred to as a *self-fulfilling prophecy* (Harber & Jussim, 2005).

Categorical Inferences

On what basis do people draw inferences? People generally use both bottom-up and top-down strategies for doing so (Holyoak & Nisbett, 1988). That is, they use both information from their sensory experiences and information based on what they already know or have inferred previously. Bottom-up strategies are based on observing various instances and considering the degree of variability across instances. From these observations, we abstract a prototype (see Chapters 8 and 9). Once a prototype or a category has been induced, the individual may use focused sampling to add new instances to the category. He or she focuses chiefly on properties that have provided useful distinctions in the past. Top-down strategies include selectively searching for constancies within many variations and selectively combining existing concepts and categories.

Reasoning by Analogy

Inductive reasoning may be applied to a broader range of situations than those requiring causal or categorical inferences. For example, inductive reasoning may be applied to reasoning by analogy.

An application of analogies in reasoning can be seen in politics. Analogies can help governing bodies come to conclusions (Breuning, 2003). These analogies also can be used effectively to convey the justification of the decision to the public (Breuning, 2003). However, the use of analogies is not always successful. This highlights both the utility and possible pitfalls of using analogies in political deliberation. In 2010, opponents of the war in Afghanistan drew an analogy to Vietnam to argue for withdrawing from Afghanistan. They asserted that the failure of U.S. policies to lead to a conclusive victory were analogous between Vietnam and Afghanistan. Some members of government then turned the tables, using an analogy to Vietnam to argue that withdrawal from Afghanistan could lead to mass slaughter, as they asserted happened in Vietnam after the Americans left. Thus, analogies can end up being made largely in the eye of the beholder rather than supporting the actual elements being compared. Analogies are used in everyday life as we make predictions about our environment. We connect our perceptions with our memories by means of analogies. The analogies then activate concepts and items stored in our mind that are similar to the current input. Through this activation, we can make a prediction of what is likely in a given situation (Bar, 2007). For example, predictions about global warming are being guided in part by people drawing analogies to times in the past when people believed either that the atmosphere warmed up or did not. Whether a given individual believes in global warming depends in part upon what analogy or analogies the individual decides to draw.

CONCEPT CHECK

1. What is inductive reasoning?
2. Which strategies do people use to draw inferences?
3. What is an analogy?
4. What leads analogies to succeed or fail?

An Alternative View of Reasoning

By now you have reasonably inferred that cognitive psychologists often disagree—sometimes rather heatedly—about how and why people reason as they do. An alternative perspective on reasoning, *dual-process theory,* contends that two complementary systems of reasoning can be distinguished. The first is an *associative system*, which involves mental operations based on observed similarities and temporal contiguities (i.e., tendencies for things to occur close together in time). The second is a *rule-based system*, which involves manipulations based on the relations among symbols (Barrett, Tugade, & Engle, 2004; Kahneman, 2013; Sloman, 1996).

The associative system can lead to speedy responses that are highly sensitive to patterns and to general tendencies. Through this system, we detect similarities between observed patterns and patterns stored in memory. We may pay more attention to salient features (e.g., highly typical or highly atypical ones) than to defining features of a pattern. This system imposes rather loose constraints that may inhibit the selection of patterns that are poor matches to the observed pattern. It favors remembered patterns that are better matches to the observed pattern. An example of associative reasoning is use of the representativeness heuristic.

Another example is the *belief bias effect* in syllogistic reasoning (Markovits, Saelen, & Forgues, 2009; Tsujii et al., 2010). This effect occurs when we agree more with syllogisms that affirm our beliefs, whether or not these syllogisms are logically valid. An example of the workings of the associative system may be in the *false consensus effect*. In this system, people believe that their own behavior and judgments are more common and more appropriate than those of other people (Ross, Greene, & House, 1977). Suppose people have an opinion on an issue. They are likely to believe that because it is their opinion, it is likely to be shared and believed to be correct by others (Dawes & Mulford, 1996; Krueger, 1998). Associating other views with our views simply because they match our own is a questionable practice, however.

The rule-based system of reasoning usually requires more deliberate, and sometimes painstaking, procedures for reaching conclusions. Through this system, we carefully analyze relevant features (e.g., defining features) of the available data based on rules stored in memory. This system imposes rigid constraints that rule out possibilities that violate the rules. Evidence in favor of rule-based reasoning includes the following:

1. We can recognize logical arguments when they are explained to us.
2. We can recognize the need to make categorizations based on defining features despite similarities in typical features. For example, we can recognize that a coin with a 3-inch diameter, which looks exactly like a quarter, must be a counterfeit.
3. We can rule out impossibilities, such as cats conceiving and giving birth to puppies.
4. We can recognize many improbabilities. For example, it is unlikely that the U.S. Congress will pass a law that provides annual salaries to all full-time college students.

According to Sloman (1996), we need both complementary systems. We need to respond quickly and easily to everyday situations on the basis of observed similarities and temporal contiguities. Yet we also need a means to evaluate our responses more deliberately.

The two systems may be conceptualized within a connectionist framework (Sloman, 1996). The associative system is represented easily in terms of pattern activation and inhibition, which readily fits the connectionist model. The rule-based system may be represented as a system of production rules (see Chapter 8).

An alternative connectionist view suggests that deductive reasoning may occur when a given pattern of activation in one set of nodes (e.g., those associated with a particular premise or set of premises) entails or produces a particular pattern of activation in a second set of nodes (Rips, 1994). Similarly, a connectionist model of inductive reasoning may involve the repeated activation of a series of similar patterns across various instances. This repeated activation then may strengthen the links among the activated nodes. It thereby leads to generalization or abstraction of the pattern for a variety of instances.

Connectionist models of reasoning and the other approaches described in this chapter offer diverse views of the available data regarding how we reason and make judgments. At present, no one theoretical model explains all the data well. But each model explains at least some of the data satisfactorily. Together, the theories help us understand human intelligence and cognition.

Consider a concrete example of the interface between intelligence and cognition in *Investigating Cognitive Psychology: When There Is No "Right" Choice.*

CONCEPT CHECK

1. What are the two complementary systems of reasoning?
2. How does a connectionist model conceptualize deductive reasoning?

Neuroscience of Reasoning

As in both problem solving and decision making, the process of reasoning involves the prefrontal cortex (Bunge et al., 2004). Furthermore, reasoning involves brain areas associated with working memory, such as the basal ganglia (Melrose, Poulin, & Stern, 2007). One would expect working memory to be involved because reasoning involves the integration of information (which needs to be held in working memory while it is being integrated).

The basal ganglia are involved in a variety of functions, including cognition and learning. This area is also associated with the prefrontal cortex through a variety of connections (Melrose, Poulin, & Stern, 2007).

When a person is presented with a statement that is either to be remembered, on the one hand, or to be used for reasoning, on the other, the processes in the brain do differ somewhat. This means there may be more going on than encoding for recall when a person knows he or she will have to reason with a statement. In particular, the left lateral frontal lobe (Broca's areas 44 and 45) is more active for syllogistic reasoning than for simply remembering a statement. This activation cannot be found for processing of conditional premises.

INVESTIGATING COGNITIVE PSYCHOLOGY

When There Is No "Right" Choice

Consider this passage from Shakespeare's *Macbeth:*

> First Apparition: *Macbeth! Macbeth! Beware Macduff; Beware the thane of Fife. Dismiss me: enough . . .*
>
> Second Apparition: *Be bloody, bold, and resolute; laugh to scorn the power of man, for none of woman born shall harm Macbeth.*
>
> Macbeth: *Then live, Macduff: what need I fear of thee? But yet I'll make assurance double sure, and take a bond of fate: thou shalt not live; that I may tell pale hearted fear it lies, and sleep in spite of thunder.*

In this passage, Macbeth mistakenly took the Second Apparition's vision to mean that no man could kill him, so he boldly decided to confront Macduff. However, Macduff was born by abdominal (Cesarean) delivery, so he did not fall into the category of men who could not harm Macbeth. Macduff eventually killed Macbeth because Macbeth came to an incorrect conclusion based on the Second Apparition's premonition. The First Apparition's warning about Macduff should have been heeded.

Suppose you are trying to decide between buying an SUV or a subcompact car. You would like the room of the SUV, but you would like the fuel efficiency of the subcompact car. Whichever you choose, how do you know whether you made the right choice? This is a difficult question to answer because most of our decisions are made under conditions of uncertainty. Thus, let us say that you bought the SUV. You can carry a number of people, you have the power to pull a trailer easily up a hill, and you sit higher so your road vision is much better. However, every time you fill up the gas tank, you are reminded of how much fuel this vehicle takes. On the other hand, let us say that you bought the subcompact car. When picking up friends at the airport, you have difficulty fitting all of them and their luggage; you cannot pull trailers up hills (or at least, not very easily); and you sit so low that when there is an SUV in front of you, you can hardly see what is on the road. However, every time you fill up your gas tank or hear someone with an SUV complaining about how much it costs to fill up his or her tank, you see how little you have to pay for gas. Again, did you make the right choice? There are no "right" or "wrong" answers to most of the decisions we make. We use our best judgment at the time of our decisions and think that they are more nearly right than wrong as opposed to definitively right or wrong.

While people were engaged in the integration of the information (solving the syllogistic and conditional reasoning problems), the left fronto-lateral cortex as well as the basal ganglia were activated for both conditional and syllogistic reasoning. However, syllogistic reasoning also involved activation in the lateral parietal cortex, precuneus, and left ventral fronto-lateral cortex (Reverberi et al., 2010). Thus, syllogistic and conditional reasoning seem to involve processing in different parts of the brain.

Exploration of conditional reasoning through event-related potential (ERP) methods revealed an increased negativity in the anterior cingulate cortex approximately 600 milliseconds and 2,000 milliseconds after task presentation (Qui et al., 2007). This negativity suggests increased cognitive control, as would be expected in a reasoning task.

In one study exploring moral reasoning in people who show antisocial behaviors indicative of poor moral reasoning, malfunctions were noted in several areas within the prefrontal cortex, including the dorsal and ventral regions (Raine & Yang, 2006). Additionally, impairments in the amygdala, hippocampus, angular gyrus, anterior cingulate, and temporal cortex also were observed. Recall that the anterior cingulate is involved in decision making and the hippocampus is involved in working memory. Therefore, it is to be expected that malfunctions in these areas would result in deficiencies in reasoning.

CONCEPT CHECK

1. Which parts of the brain are prominently involved in reasoning processes?
2. Why can we expect that the parts of the brain that are involved in working memory are also active during reasoning?

Key Themes

Several of the themes discussed in Chapter 1 are relevant to this chapter.

Rationalism versus empiricism. One way to understand errors in syllogistic reasoning is in terms of the particular logical error made, independently of the mental processes the reasoner has used. For example, affirming the consequent is a logical error. One need do no empirical research to understand at the level of symbolic logic the errors that have been made. Moreover, deductive reasoning is itself based on rationalism. A syllogism such as, "All toys are chairs. All chairs are hot dogs. Therefore, all toys are hot dogs," is logically valid but factually incorrect. Thus, deductive logic can be understood at a rational level, independently of its empirical content. But if we wish to know psychologically why people make errors or what is factually true, then we need to combine empirical observations with rational logic.

Domain generality versus domain specificity. The rules of deductive logic apply equally in all domains. One can apply them, for example, to abstract or to concrete content. But research has shown that, psychologically, deductive reasoning with concrete content is easier than reasoning with abstract content. So although the rules apply in exactly the same way generally across domains, ease of application is not psychologically equivalent across those domains.

Nature versus nurture. Are people preprogrammed to be logical thinkers? Piaget, the famous Swiss cognitive developmental psychologist, believed so. He believed that the development of logical thinking follows an inborn sequence of stages that unfold over time. According to Piaget, there is not much one can do to alter either the sequence or timing of these stages. But research has suggested that the sequence Piaget proposed does not unfold as he thought. For example, many people never reach his highest stage, and some children are able to reason in ways he would not have predicted they would be able to reason until they were older. So once again, nature and nurture interact.

SUMMARY

1. **What are some of the strategies that guide human decision making?** Early theories were designed to achieve practical mathematical models of decision making and assumed that decision makers are fully informed, infinitely sensitive to information, and completely rational. Subsequent theories began to acknowledge that humans often use subjective criteria for decision making, that chance elements often influence the outcomes of decisions, that humans often use subjective estimates for considering the outcomes, and that humans are not boundlessly rational in making decisions. People apparently often use satisficing strategies, settling for the first minimally acceptable option, and strategies involving a process of elimination by aspects to eliminate an overabundance of options.

   One of the most common heuristics most of us use is the representativeness heuristic. We fall prey to the fallacious belief that small samples of a population resemble the whole population in all respects. Our misunderstanding of base rates and other aspects of probability often leads us to other mental shortcuts as well, such as in the conjunction fallacy and the inclusion fallacy.

   Another common heuristic is the availability heuristic, in which we make judgments based on information that is readily available in memory, without bothering to seek less available information. The use of heuristics, such as anchoring and adjustment, illusory correlation, and framing effects, also often impairs our ability to make effective decisions.

   Once we have made a decision (or better yet, another person has made a decision) and the outcome of the decision is known, we may engage in hindsight bias, skewing our perception of the earlier evidence in light of the eventual outcome. Perhaps the most serious of our mental biases, however, is overconfidence, which seems to be amazingly resistant to evidence of our own errors.
2. **What are some of the forms of deductive reasoning that people may use, and what factors facilitate or impede deductive reasoning?** Deductive reasoning involves reaching conclusions from a set of conditional propositions or from a syllogistic pair of premises. Among the various types of syllogisms are linear syllogisms and categorical syllogisms. In addition, deductive reasoning may involve complex transitive inference problems or mathematical or logical proofs involving large numbers of terms. Also, deductive reasoning may involve the use of pragmatic reasoning schemas in practical, everyday situations.

   In drawing conclusions from conditional propositions, people readily apply the *modus ponens* argument, particularly regarding universal affirmative propositions. Most of us have more difficulty, however, in using the *modus tollens* argument and in avoiding deductive fallacies, such as affirming the consequent or denying the antecedent, particularly when faced with propositions involving particular propositions or negative propositions.

   In solving syllogisms, we have similar difficulties with particular premises and negative premises and with terms that are not presented in the customary sequence. Frequently, when trying to draw conclusions, we overextend a strategy from a situation in which it leads to a deductively valid conclusion to one in which it leads to a deductive fallacy. We also may foreclose on a given conclusion before considering the full range of possibilities that may affect the conclusion. These mental shortcuts may be exacerbated by situations in which we engage in confirmation bias (tending to confirm our own beliefs). We can enhance our ability to draw well-reasoned conclusions in many ways, such as by taking time to evaluate the premises or propositions carefully and by forming multiple mental models of the propositions and their relationships. We also may benefit from training and practice in effective deductive reasoning. We are particularly likely to reach well-reasoned conclusions when such conclusions seem plausible and useful in pragmatic contexts, such as during social exchanges.

3. **How do people use inductive reasoning to reach causal inferences and to reach other types of conclusions?** Although we cannot reach logically certain conclusions through inductive reasoning, we can at least reach highly probable conclusions through careful reasoning. When making categorical inferences, people tend to use both top-down and bottom-up strategies. Processes of inductive reasoning generally form the basis of scientific study and hypothesis testing as a means to derive causal inferences. In addition, in reasoning by analogy, people often spend more time encoding the terms of the problem than in performing the inductive reasoning. Reasoning by analogy can lead to better conclusions, but also to worse ones if the analogy is weak or based on faulty assumptions. It appears that people sometimes may use reasoning based on formal rule systems, such as by applying rules of formal logic, and sometimes may use reasoning based on associations, such as by noticing similarities and temporal contiguities.
4. **Are there any alternative views of reasoning?** A number of scientists have suggested that people have two distinct systems of reasoning: an associative system that is sensitive to observed similarities and temporal contiguities and a rule-based system that involves manipulations based on relations among symbols. The two systems can work together to help us reach reasonable conclusions in an efficient way.

THINKING ABOUT THINKING: ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Describe some of the heuristics and biases people use while making judgments or reaching decisions.
2. What are the two logical arguments and the two logical fallacies associated with conditional reasoning, as in the Wason Selection Task?
3. Which of the various approaches to conditional reasoning seems best to explain the available data? Give reasons for your answer.
4. Some cognitive psychologists question the merits of studying logical formalisms, such as linear or categorical syllogisms. What do you think can be gained by studying how people reason in regard to syllogisms?
5. Using the information in this chapter, design a way to help high school students more effectively apply deductive reasoning to the problems they face.
6. Design a question, such as the ones used by Kahneman and Tversky, which requires people to estimate subjective probabilities of two different events. Indicate the fallacies that you may expect to influence people's estimates, or explain why you think people would give realistic estimates of probability.
7. Suppose that you need to rent an apartment. How would you go about finding one that most effectively meets your requirements and your preferences?

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How closely does your method resemble the methods described by subjective expected utility theory, by satisficing, or by elimination by aspects?

8. Give two examples showing how you use rule-based reasoning and associative reasoning in your everyday experiences. In what kinds of instances do you believe each type of reasoning works better, or not as well?

KEY TERMS

availability heuristic, p. 446
base rate, p. 446
bounded rationality, p. 442
categorical syllogism, p. 465
causal inferences, p. 470
conditional reasoning, p. 460
confirmation bias, p. 468
deductive reasoning, p. 459
deductive validity, p. 460
elimination by aspects, p. 443
fallacy, p. 441
heuristics, p. 442
hindsight bias, p. 451
illusory correlation, p. 450
inductive reasoning, p. 469
judgment and decision making, p. 441
mental model, p. 467
overconfidence, p. 450
pragmatic reasoning schema, p. 464
premises, p. 459
proposition, p. 459
reasoning, p. 459
representativeness, p. 445
satisficing, p. 443
subjective probability, p. 442
subjective utility, p. 442
syllogisms, p. 465

MEDIA RESOURCES

CogLab

Explore the following experiments in CogLab:

Lab 51—Risky Decisions
Lab 52—Typical Reasoning
Lab 53—Wason Selection Task

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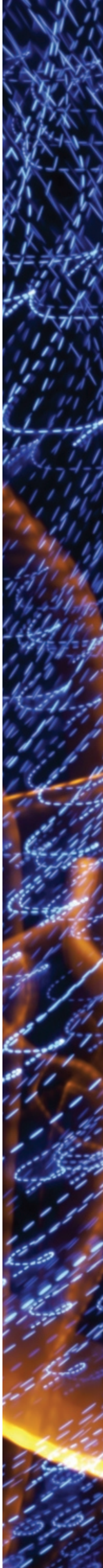
Human Intelligence

13



CHAPTER OUTLINE

- **Measures and Structures of Intelligence**
  - Spearman: The “g” Factor
  - Thurstone: Primary Mental Abilities
  - Cattell, Vernon, and Carroll: Hierarchical Models
- **Information Processing and Intelligence**
  - Process-Timing Theories
    - Choice Reaction Time
    - Lexical-Access Speed and Speed of Simultaneous Processing
  - Working Memory
  - Componential Theory and Complex Problem Solving
    - An Integrative Approach
  - Biological Bases of Intelligence
- **Alternative Approaches to Intelligence**
  - Cultural Context and Intelligence
  - Gardner: Multiple Intelligences
  - Sternberg: The Triarchic Theory
    - How Intelligence Relates to the Internal World
    - How Intelligence Relates to Experience
    - How Intelligence Relates to the External World
- **Improving Intelligence: Effective, Ineffective, and Questionable Strategies**
  - Improving Children’s Intelligence
  - Development of Intelligence in Adults
- **Artificial Intelligence: Computer Simulations**
  - Can a Computer Program Be “Intelligent”?
    - The Turing Test
  - Applications of Artificial Intelligence
  - Intelligence versus the Appearance of Intelligence
- **Key Themes**
- **Summary**
- **Thinking about Thinking: Factual, Analytical, Creative, and Practical Questions**
- **Key Terms**

Here are some questions we will explore in this chapter:

1. What are the key issues in measuring intelligence? How do different researchers and theorists approach the issues?
2. What are some information-processing approaches to intelligence?
3. What are some alternative views of intelligence?
4. How have researchers attempted to simulate intelligence using machines such as computers?
5. Can intelligence be improved, and if so, how?
6. How does intelligence develop in adults?

BELIEVE IT OR NOT | Can Our Expectations Really Affect Our Cognitive Performance?

Intelligence can be improved by training people to remember, represent information, and reason. One factor, however, greatly affects intelligence and performance: the belief that intelligence is changeable. Math students who believed in the malleability of intelligence showed an increase in math achievement over two years, whereas those who did not believe in the malleability of intelligence did not experience a significant increase in achievement. Additionally, math students with declining grades who were taught that intelligence is changeable were able to stop the decline of their grades compared with their peers (Blackwell, Trzesniewski, & Dweck, 2007). In other words, not only intelligence itself, but also beliefs about intelligence affect how intelligence shows itself in academic performance.

Human intelligence can be viewed as an integrating, or "umbrella," psychological construct for a great deal of theory and research in cognitive psychology. Intelligence is the capacity to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the surrounding environment. It may require different adaptations within different social and cultural contexts. People who are more intelligent tend to be superior in processes such as divided and selective attention, working memory, reasoning, problem solving, decision making, and concept formation. So when we come to understand the mental processes involved in each of these cognitive functions, we also better understand the bases of individual differences in human intelligence.

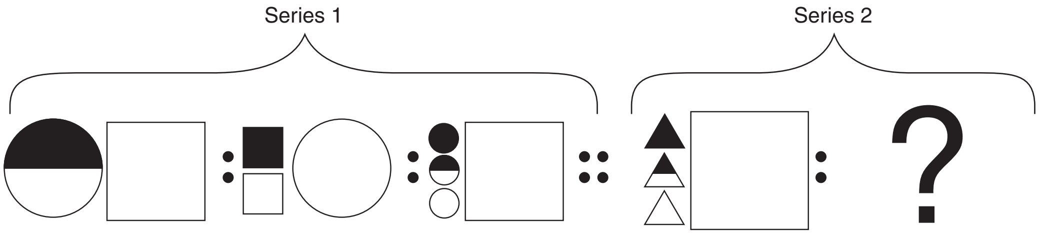
Each of the tasks in the *Investigating Cognitive Psychology* feature is believed, at least by some cognitive psychologists, to require some degree of intelligence. Intelligence is a concept that can be viewed as tying together all of cognitive psychology. Just what is intelligence? In a recent article, researchers identified approximately 70 different definitions of intelligence (Legg & Hutter, 2007). In 1921, when the editors of the *Journal of Educational Psychology* asked 14 famous psychologists that question, the responses varied but generally embraced these two themes. First, intelligence involves the capacity to learn from experience. Second, it involves the ability to adapt to the surrounding environment. Sixty-five years later, 24 cognitive psychologists with expertise in intelligence research were asked the same question (Sternberg & Detterman, 1986). They, too, underscored the importance of learning from experience and adapting to the environment. They also broadened the definition to emphasize the importance of

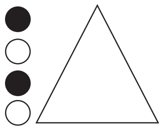
INVESTIGATING COGNITIVE PSYCHOLOGY

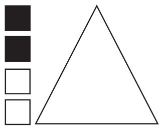
Intelligence

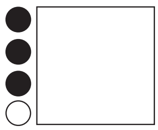
Before you read about how cognitive psychologists view intelligence, try responding to a few tasks that require you to use your own intelligence:

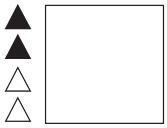
1. Candle is to tallow as tire is to (a) automobile, (b) round, (c) rubber, (d) hollow.
2. Complete this series: 100%, 0.75, 1⁄2; (a) whole, (b) one eighth, (c) one fourth.
3. The first three items form one series. Complete the analogous second series that starts with the fourth item:











Answer options: **(a)** **(b)** **(c)** **(d)**

4. You are at a party of truth-tellers and liars. The truth-tellers always tell the truth, and the liars always lie. You meet someone new. He tells you that he just heard a conversation in which a girl said she was a liar. Is the person you met a liar or a truth-teller?

Source: Sternberg, *Cognitive Psychology* 5e, page 529.

metacognition—people's understanding and control of their own thinking processes. Contemporary experts also more heavily emphasized the role of culture. They pointed out that what is considered intelligent in one culture may be considered less intelligent in another culture (Ang, Van Dyne, & Tan, 2011; Serpell, 2000). **Intelligence** is the capacity to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the surrounding environment. It may require different adaptations within different social and cultural contexts (Niu & Brass, 2011; Saklofske et al., 2015; Sternberg, 2004).

Most of us have our own implicit (unstated) ideas about what it means to be smart. That is, we have our own *implicit theories* (usually unstated conceptions) of intelligence. We use our implicit theories in many social situations. For example, we use them when we meet people and evaluate their intelligence. We also use them when we describe people we know as being very smart or not so smart (Grigorenko et al., 2001; Sternberg, 1985b).

Within our implicit theories of intelligence, we also recognize that intelligence has somewhat different meanings in different contexts. A smart salesperson may show a different kind of intelligence than a smart neurosurgeon or a smart accountant. Each of them may show a different kind of intelligence than a smart choreographer, composer, athlete, or sculptor. Often, we use our implicit and context-relevant definitions of intelligence to make assessments of intelligence. Is your mechanic smart enough to

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find and fix the problem in your car? Is your physician smart enough to find and treat your health problem? Is this attractive person smart enough to hold your interest in a conversation?

Implicit theories of intelligence may differ from one culture to another. For example, there is evidence that Chinese people in Taiwan include interpersonal and intrapersonal (self-understanding) skills as part of their conception of intelligence (Yang & Sternberg, 1997). Rural Kenyan conceptions of intelligence encompass moral as well as cognitive skills (Grigorenko et al., 2001). Thus, what might count as a comprehensive assessment of intelligence could differ from one culture to another (Sternberg & Kaufman, 1998). Even within the United States, many people have started viewing the emotional aspects of intelligence as important as the cognitive aspects of intelligence. **Emotional intelligence** is "the ability to perceive and express emotion, assimilate emotion in thought, understand and reason with emotion, and regulate emotion in the self and others" (Mayer, Salovey, & Caruso, 2000, p. 396). There is good evidence for the existence of some kind of emotional intelligence (Cherniss et al., 2006; Ciarrochi, Forgas, & Mayer, 2001; Mayer, 2014; Mayer & Salovey, 1997; Salovey & Sluyter, 1997), although the evidence is mixed (Davies, Stankov, & Roberts, 1998; Waterhouse, 2006). The concept of emotional intelligence has also become popular in recent years (Goleman, 1995, 1998; Goleman, Boyatzis, & McKee, 2013; Stein & Deonarine, 2015). Some evidence suggests that emotional intelligence is a strong predictor of successful adaptation to new environments (e.g., college or a foreign country) and of success in one's chosen field (Gabel, Dolan, & Cerdin, 2005; Parker et al., 2006; Stein & Book, 2006). A related concept is that of social intelligence. *Social intelligence* is the ability to understand and interact with other people (Albrecht, 2009; Goleman, 2007; Boyatzis, Gaskin, & Wei, 2015; Kihlstrom & Cantor, 2000).

A number of cultural differences are evident in the definition of intelligence. These differences have led to a field of study within intelligence research that examines cultural differences in defining intelligence. This field explores what is termed *cultural intelligence,* or CQ (Ang, Van Dyne, & Tan, 2011; Sternberg & Grigorenko, 2006). This term is used to describe a person's ability to adapt to a variety of challenges in diverse cultures (Ang, Dyne, & Koh, 2006; Sternberg & Grigorenko, 2006; Triandis, 2006). Research also shows that personality variables are related to intelligence (Ackerman, 1996; DeYoung, 2011). Taken together, this evidence suggests that a comprehensive definition of intelligence incorporates many facets of intellect.

Explicit definitions of intelligence also focus on assessment. In fact, some psychologists have been content to define intelligence as whatever it is that the tests measure (Boring, 1923). This definition, unfortunately, is circular. According to it, the nature of intelligence is what is tested. But what is tested must be determined by the nature of intelligence. Moreover, what different tests of intelligence measure is not always the same thing. Different tests measure somewhat different constructs (Daniel, 2000; Kaufman, 2000; Naglieri, 2015). So it is not feasible to define intelligence by what tests measure, as though they all measured the same thing. By the way, the answers to the questions in the chapter opener are as follows:

1. Rubber. Candles are frequently made of tallow, just as tires are frequently made of (c) rubber.
2. 100%, 0.75, and 1⁄2 are quantities that successively decrease by 1⁄4; to complete the series, the answer is (c) one fourth, which is a further decrease by 1⁄4.
3. The first series was a circle and a square, followed by two squares and a circle, followed by three circles and a square; the second series was three triangles and a square, which would be followed by (b), four squares and a triangle.
4. The person you met is clearly a liar. If the girl about whom this person was talking were a truth-teller, she would have said that she was a truth-teller. If she

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were a liar, she would have lied and said that she was a truth-teller also. Thus, regardless of whether the girl was a truth-teller or a liar, she would have said that she was a truth-teller. Because the man you met has said that she said she was a liar, he must be lying and hence must be a liar.

Measures and Structures of Intelligence

Contemporary measurements of intelligence usually can be traced to one of two different historical traditions. One tradition concentrated on lower-level, psychophysical abilities. These include sensory acuity, physical strength, and motor coordination. The other focused on higher-level, judgmental abilities. We traditionally describe these abilities as related to thinking, reasoning, and problem solving (Lohman & Lakin, 2011). Stop for a moment to think about yourself and your close associates. How would you assess yourself and your associates in terms of intelligence? When you make these assessments, do psychophysical abilities seem more important? Or do judgment abilities seem more important to you?

Francis Galton (1822–1911) believed that intelligence is a function of psychophysical abilities. For several years, Galton maintained a well-equipped laboratory where visitors could have themselves measured on a variety of psychophysical tests. These tests measured a broad range of psychophysical skills and sensitivities. One example was weight discrimination, the ability to notice small differences in the weights of objects. Another example was pitch sensitivity, the ability to hear small differences between musical notes. A third example was physical strength (Galton, 1883). One of the many enthusiastic followers of Galton attempted to detect links among the assorted tests (Wissler, 1901). He hoped such links would unify the various dimensions of psychophysically based intelligence. But he detected no unifying associations. Moreover, the psychophysical tests did not predict college grades. Thus, the psychophysical approach to assessing intelligence soon faded almost into oblivion. Nevertheless, it would reappear many years later in a somewhat different guise.

An alternative to the psychophysical approach was developed by Alfred Binet (1857–1911). He and his collaborator, Theodore Simon, also attempted to assess intelligence, but their goal was much more practical than purely scientific. Binet had been asked to devise a procedure for distinguishing normal learners from learners who are mentally retarded (Binet & Simon, 1916). Thus, Binet and his collaborator set out to measure intelligence as a function of the ability to learn within an academic setting. In Binet's view, judgment is the key to intelligence; the key, according to Binet, is not psychophysical acuity, strength, or skill.

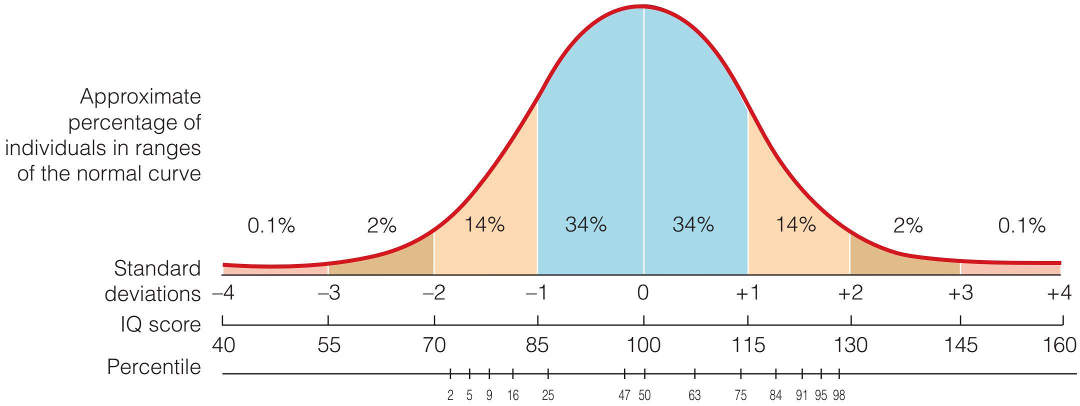
For Binet (Binet & Simon, 1916), intelligent thought (mental judgment) includes three distinct elements: direction, adaptation, and criticism (see Esping & Plucker, 2015). Think about how you are intelligently using these elements yourself at this moment: Direction involves knowing what has to be done and how to do it; adaptation refers to customizing a strategy for performing a task and then monitoring that strategy while implementing it; and criticism is your ability to critique your own thoughts and actions. The importance of direction and adaptation certainly fits with contemporary views of intelligence, and Binet's notion of criticism actually seems prescient, considering the current appreciation of metacognitive processes as a key aspect of intelligence.

Initially, when Binet and Simon developed their intelligence test, they were searching for a way to compare the intelligence of a given child with that of other children of the same chronological (physical) age. For their purposes, they sought to determine each child's *mental age*—the average level of intelligence for a person of a given age. Thus, a mental age of 7 refers to the level of thinking reached by an average 7-year-old child. Mental ages worked just fine for comparing a given 7-year-old child with other 7-year-old children, but the use of mental ages made it difficult to compare relative intelligence in children of differing chronological ages.

William Stern (1912) suggested instead that we evaluate people's intelligence by using an *intelligence quotient* (IQ): a ratio of mental age (MA) divided by chronological age (CA), multiplied by 100 (Figure 13.1 ■). This ratio can be expressed mathematically as follows: IQ = (MA/CA)(100). Thus, if Joan's mental age of 5 equals her chronological age of 5, then her intelligence is average and her IQ is 100 because (5/5)(100) = 100. When mental age exceeds chronological age, the ratio will lead to an IQ score above 100, and when chronological age exceeds mental age, the ratio will lead to an IQ score below 100. Intelligence scores that are expressed in terms of a ratio of mental age to chronological age are termed *ratio IQs*.

For various reasons, ratio IQs proved inadequate. For example, increases in mental age slow down at about age 16 years. An 8-year-old child with a mental age of 12 years is pretty smart. However, do you feel sure that a 40-year-old adult with a mental age of 60 is similarly intelligent, although the ratio IQ is the same for the 8-year-old child and the 40-year-old adult? What does a mental age of 60 mean? In the 21st century, psychologists rarely use IQs based on mental ages. Instead, researchers have turned to measurement comparisons based on assumed normal distributions of test scores within large populations. Scores based on deviations from the middle score in a normal distribution of scores on a test of intelligence are termed *deviation IQs*. Many cognitive theorists believe that IQs provide an incomplete measurement of intelligence, as discussed later in this chapter.

Lewis Terman of Stanford University built on Binet and Simon's work in Europe and constructed the earliest version of what is known as the Stanford–Binet Intelligence Scale (Roid, 2003; Terman & Merrill, 1937, 1973; Thorndike, Hagen, & Sattler, 1986; Table 13.1 ■). For years, the Stanford–Binet test was the standard for intelligence tests, and it still is used widely. More widely used, however, are probably the competitive Wechsler scales, named for their creator, David Wechsler (Benisz, Dumont, & Willis, 2015).



■ **Figure 13.1** This figure shows a normal distribution as it applies to IQ, including identifying labels that are sometimes used to characterize different levels of IQ. It is important not to take these labels too seriously because they only are loose characterizations, not scientific descriptions of performance.

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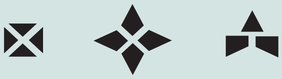
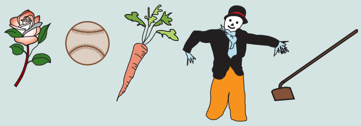
Table 13.1 **The Stanford–Binet Intelligence Scale**

The sample questions used throughout this chapter are not actual questions from any of the scales; they are intended only to illustrate the types of questions that might appear in each of the main content areas of the tests. How would you respond to these questions? What do your responses indicate about your intelligence?

Content Area	Explanation of Tasks/Questions	Example of a Possible Task/Question
Verbal Reasoning		
Vocabulary comprehension	Define the meaning of a word. Show an understanding of why the world works as it does.	What does the word *diligent* mean? Why do people sometimes borrow money?
Absurdities	Identify the odd or absurd feature of a picture.	Recognize that ice hockey players do not ice skate on lakes into which swimmers in bathing suits are diving.
Verbal relations	Tell how three of four items are similar to one another yet different from the fourth item.	Note that an apple, a banana, and an orange can be eaten, but a mug cannot be.
Quantitative Reasoning		
Number series	Complete a series of numbers.	Given the numbers 1, 3, 5, 7, 9, what number would you expect to come next?
Quantitative	Solve simple arithmetic-word problems.	If Maria has six apples, and she wants to divide them evenly among herself and her two best friends, how many apples will she give to each friend?
Figural/Abstract Reasoning		
Pattern analysis	Figure out a puzzle in which the test-taker must combine pieces representing parts of geometric shapes, fitting them together to form a particular geometric shape.	Fit together these pieces to form a (geometric shape). 
Short-Term Memory		
Memory for sentences	Listen to a sentence; then repeat it back exactly as the examiner said it.	Repeat this sentence back to me: “Harrison went to sleep late and awoke early the next morning.”
Memory for digits	Listen to a series of digits (numbers); then repeat the numbers either forward or backward or both.	Repeat these numbers backward: “9, 1, 3, 6.”
Memory for objects	Watch the examiner point to a series of objects in a picture; then point to the same objects in exactly the same sequence in which the examiner did so.	Point to the carrot, then the hoe, then the flower, then the scarecrow, and then the baseball. 

Images Source: Sternberg, *Cognitive Psychology*, 5e, Page 534, last column of Table 13.1.

There are three levels of the Wechsler intelligence scales, including the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008), the fourth edition of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), and the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III; Wechsler, 2002). Historically, the Wechsler adult tests yielded three scores: a verbal score, a performance

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score, and an overall score. The verbal score is based on tests such as vocabulary and verbal similarities. In verbal similarities, the test-taker has to say how two things are similar. The performance score is based on several tests. One is picture completion, which requires identification of a missing part in a picture of an object. Another is picture arrangement, which requires rearrangement of a scrambled set of cartoon-like pictures into an order that tells a coherent story. The overall score is a combination of the verbal and the performance scores. More recently (in the fourth edition), the scoring system has been changed to yield a different set of scores more consistent with theorizing in cognitive psychology: verbal comprehension, perceptual reasoning, working memory, and processing speed. Table 13.2 ■ shows the types of items from each of the Wechsler adult-scale subtests, which you may wish to compare with those of the Stanford–Binet.

Wechsler, like Binet, had a conception of intelligence that went beyond what his own test measured. Wechsler clearly believed in the worth of attempting to measure intelligence. But he did not limit his conception of intelligence to test scores. Wechsler believed that intelligence is central in our everyday lives. Intelligence is not represented just by a test score or even by what we do in school. We use our intelligence not only in taking tests and in doing homework but also in relating to people, in performing our jobs effectively, and in managing our lives in general.

A focus on measuring intelligence is only one of several approaches to theory and research on intelligence. Issues related to the approach to studying intelligence are discussed in earlier chapters in this book. One issue is whether cognitive psychologists should focus on the measurement of intelligence or on the processes of intelligence. A second issue is what underlies intelligence: a person's genetic inheritance, a person's acquired attributes, or some kind of interaction between the two. Modern psychologists overwhelmingly accept the notion that intelligence derives from an interaction of genetic and environmental factors (Deary, Johnson, & Houlihan, 2009; Mandelman & Grigorenko, 2011)

Psychologists interested in the structure of intelligence have relied on factor analysis as the indispensable tool for their research. **Factor analysis** is a statistical method for separating a construct—intelligence in this case—into a number of hypothetical factors or abilities that the researchers believe form the basis of individual differences in test performance (Willis, Dumont, & Kaufman, 2011). The specific factors derived, of course, still depend on the specific questions being asked and the tasks being evaluated.

Factor analysis is based on studies of correlation. The idea is that the more highly two tests are correlated, the more likely they are to measure the same thing. In research on intelligence, a factor analysis might involve these steps. First, give a large number of people several different tests of ability. Second, determine the correlations among all of those tests. Third, statistically analyze those correlations to simplify them into a relatively small number of factors that summarize people's performance on the tests. The investigators in this area generally have agreed on and followed this procedure. Yet the resulting factorial structures of intelligence have differed among different theorists. Among the many competing factorial theories, the main ones probably have been those of Spearman, Thurstone, Guilford, Cattell, Vernon, and Carroll (see review in Schneider & Flanagan, 2015). Figure 13.2 ■ contrasts four of these theories.

Spearman: The "g" Factor

Charles Spearman (1863–1945) is credited with inventing factor analysis (Spearman, 1927). Using factor-analytic studies, Spearman concluded that intelligence can be understood in terms of two kinds of factors. A single general factor pervades performance on all tests of mental ability. A set of specific factors is involved in performance on only a single type of mental-ability test (e.g., arithmetic computations). In Spearman's view, the

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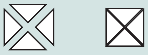
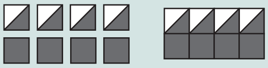
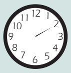
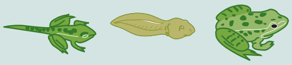
Table 13.2 The Wechsler Adult Intelligence Scale

Based on the content areas and the kinds of questions shown here, how does the Wechsler differ from the Stanford–Binet?

Content Area	Explanation of Tasks/Questions	Example of a Possible Task/Question
Verbal Scale		
Comprehension	Answer questions of social knowledge.	What does it mean when people say, "A stitch in time saves nine"? Why are convicted criminals put into prison?
Vocabulary	Define the meaning of a word.	What does *persistent* mean? What does *archaeology* mean?
Information	Supply generally known information.	Who is Michelle Obama? What are six New England states?
Similarities	Explain how two things or concepts are similar.	In what ways are an ostrich and a penguin alike? In what ways are a lamp and a heater alike?
Arithmetic	Solve simple arithmetic-word problems.	If Paul has $14.43, and he buys two sandwiches that cost $5.23 each, how much change will he receive? How many hours will it take to travel 1,200 miles if you are traveling 60 miles per hour?
Digit span	Listen to a series of digits (numbers); then repeat the numbers either forward, backward, or both.	Repeat these numbers backward: "9, 1, 8, 3, 6." Repeat these numbers, just as I am telling you: "6, 9, 3, 2, 8."
Performance Scale		
Object assembly	Put together a puzzle by combining pieces to form a particular common object.	Put together these pieces to make something. 
Block design	Use patterned blocks to form a design that looks identical to a design shown by the examiner.	Assemble the blocks at the left to match the design at the right. 
Picture completion	Tell what is missing from each picture.	What is missing from this picture? 
Picture arrangement	Put a set of cartoon-like pictures into chronological order so that they tell a coherent story.	Arrange these pictures in an order that tells a story, and then tell what is happening in the story. 
Digit symbol	When given a key matching particular symbols to particular numerals, use the sequence of symbols to transcribe from symbols to numerals using the key.	Look carefully at the key, showing which symbols correspond to which numerals. In the blanks, write the correct numeral for the symbol above each blank. ○ □ ⊗ ◇ ⊖ 1 2 3 4 5 □ ◇ ⊖ □ ○ ⊗ ◇ ⊖ _ _ _ _ _ _ _ _

Images Source: Sternberg, *Cognitive Psychology*, 5e, Page 535, last column of Table 13.2.

specific factors are of only casual interest because of the narrow applicability of these factors. To Spearman, the general factor, which he labeled the **"g" factor**, provides the key to understanding intelligence. Spearman believed "g" to be the result of "mental energy." Many psychologists still believe Spearman's theory to be essentially correct (e.g., Jensen, 1998; see essays in Sternberg & Grigorenko, 2013).

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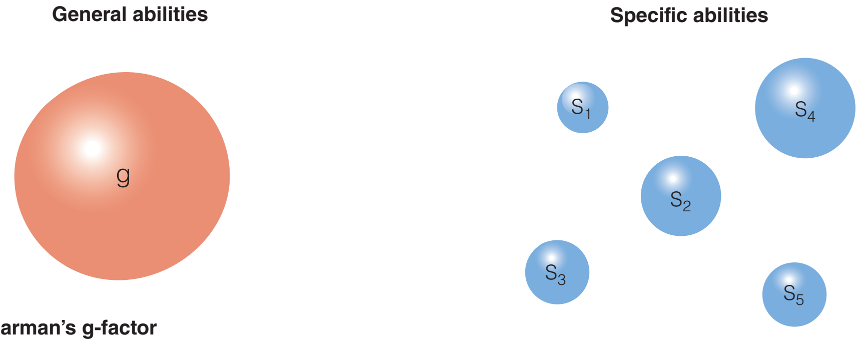
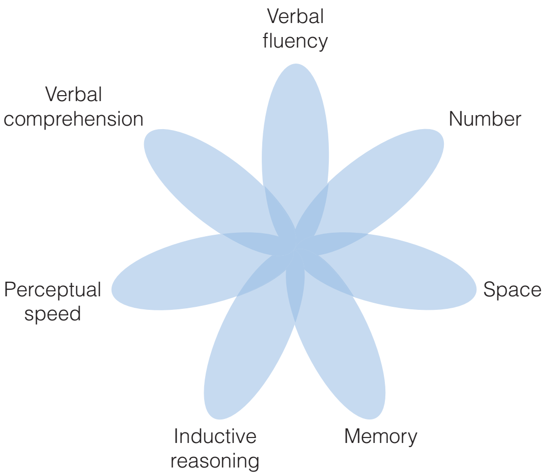
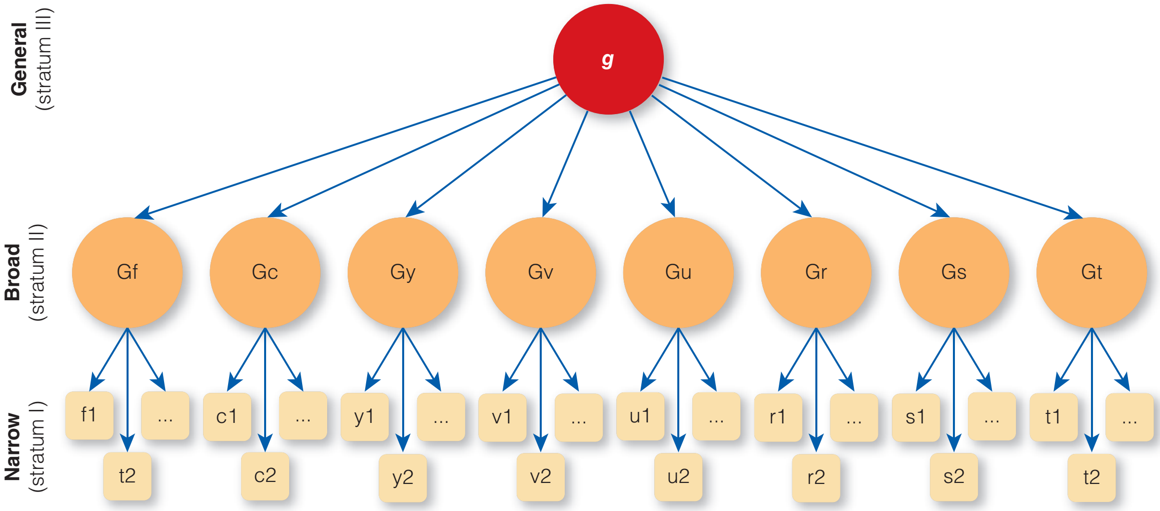

General abilities
g
Specific abilities
S_1
S_4
S_2
S_3
S_5

(a) Spearman's g-factor


Verbal fluency
Verbal comprehension
Number
Perceptual speed
Space
Inductive reasoning
Memory

(b) Thurstone's model


General (stratum III)
g
Broad (stratum II)
Gf
Gc
Gy
Gv
Gu
Gr
Gs
Gt
Narrow (stratum I)
f1
...
t2
c1
...
c2
y1
...
y2
v1
...
v2
u1
...
u2
r1
...
r2
s1
...
s2
t1
...
t2

(c) Carroll's model

Figure 13.2 Although Spearman, Thurstone, and Carroll all used factor analysis to determine the factors underlying intelligence, they all reached different conclusions regarding the structure of intelligence. Which model most simply yet comprehensively describes the structure of intelligence as you understand it? How do particular models of intelligence shape our understanding of intelligence?

Source: Based on *In Search of the Human Mind*, by Robert J. Sternberg. Copyright © 1995 by Harcourt Brace & Company.

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Thurstone: Primary Mental Abilities

In contrast to Spearman, Louis Thurstone (1887–1955) concluded that the core of intelligence resides not in one single factor but in seven such factors (Thurstone, 1938). He referred to them as primary mental abilities. According to Thurstone, the primary mental abilities are as follows:

1. *Verbal comprehension:* measured by vocabulary tests
2. *Verbal fluency:* measured by time-limited tests requiring the test-taker to think of as many words as possible that begin with a given letter
3. *Inductive reasoning:* measured by tests such as analogies and number-series completion tasks
4. *Spatial visualization:* measured by tests requiring mental rotation of pictures of objects
5. *Number:* measured by computation and simple mathematical problem-solving tests
6. *Memory:* measured by picture and word-recall tests
7. *Perceptual speed:* measured by tests that require the test-taker to recognize small differences in pictures or to cross out the differences in strings of varied letters

These components provide a direct means to measure intelligence as defined by Thurstone (1938). The measure of intelligence is still used by some experimenters to assess intellectual abilities (Vigil-Colet & Morales-Vives, 2005).

Cattell, Vernon, and Carroll: Hierarchical Models

An economical way of handling a number of factors of the mind is through a hierarchical model of intelligence. One such model proposed that general intelligence comprises two major subfactors. They are fluid ability and crystallized ability. Fluid ability is speed and accuracy of abstract reasoning, especially for novel problems. Crystallized ability is accumulated knowledge and vocabulary (Cattell, 1971). Subsumed within these two major subfactors are other, more specific factors. A similar view is a general division between practical-mechanical and verbal-educational abilities (Vernon, 1971).

A more recent model is a hierarchy composed of three strata (Carroll, 1993). Stratum I includes many narrow, specific abilities (e.g., spelling ability, speed of reasoning). Stratum II includes various broad abilities (e.g., fluid intelligence, crystallized intelligence). And Stratum III is just a single general intelligence, much like Spearman's "g" factor. Of these strata, the most interesting is the middle stratum, which is neither too narrow nor too all encompassing.

In addition to fluid intelligence and crystallized intelligence, Carroll includes in the middle stratum several other abilities. They are learning and memory processes, visual perception, auditory perception, facile production of ideas (similar to verbal fluency), and speed (which includes both sheer speed of response and speed of accurate responding). Carroll's model is probably the most widely accepted of the psychometric models.

Johnson and Bouchard (2005) proposed a variation of hierarchical theory in which they suggested that abilities are properly divided not into fluid and crystallized, but rather into verbal, perceptual, and image rotation. Their argument is that spatial abilities such as the ability to rotate images of objects in the mind are relatively distinct from either fluid or crystallized intelligence. Whereas the factor-analytic approach this theory exemplifies has tended to emphasize the structures of intelligence, the information-processing approach has tended to emphasize the operations of intelligence.

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Information Processing and Intelligence

Information-processing theorists study how people mentally manipulate what they learn and know about the world (Hunt, 2005; Mackintosh, 2011). The ways in which various information-processing investigators study intelligence differ primarily in terms of the complexity of the processes being studied (Lohman & Lakin, 2011; Stankov, 2005). Researchers have considered both the speed and the accuracy of information processing to be important factors in intelligence.

Process-Timing Theories

Inspection time is the amount of time it takes you to inspect items and make a decision about them. It is measured through an inspection-time experimental paradigm (Nettelbeck, 1987, 2011; see also Deary, 2000; Deary & Stough, 1996; Neubauer & Fink, 2005). Here is a typical use of the paradigm. For each of a number of trials, a computer monitor displays a fixation cue (a dot in the area where a target figure will appear) for 500 milliseconds. There is then a pause of 360 milliseconds. Following this period, the computer presents the target stimulus for a particular interval of time. Finally, it presents a visual mask (a stimulus that erases the trace in iconic memory).

The target stimulus typically includes two vertical lines of unequal length. For example, one might be 25 millimeters and the other 35 millimeters. The two lines are aligned at the top by a horizontal crossbar. The shorter of the two lines may appear on either the right or the left side of the stimulus. The visual mask is a pair of lines that are thicker and longer than the two lines of the target stimulus. The task is to inspect the target stimulus and then indicate the side on which the shorter line appeared. One indicates the left-hand stimulus by pressing a left-hand button on a keypad connected to a computer that records the responses. One indicates the right-hand stimulus by pressing the right-hand button.

The key variable is the length of time for the presentation of the target stimulus, not the speed of responding by pressing the button. Nettelbeck defined inspection time operationally. It is the length of time for presentation of the target stimulus after which the participant still responds with at least 90% accuracy in indicating the side on which the shorter line appeared. He found that shorter inspection times correlate with higher scores on intelligence tests (e.g., various subscales of the WAIS) among differing populations of participants (Nettelbeck, 1987, 2011).

Choice Reaction Time

Some investigators have proposed that intelligence can be understood in terms of speed of neuronal conduction (e.g., Jensen, 1979, 1998; see Nettelbeck, 2011). In other words, the smart person is someone whose neural circuits conduct information rapidly. When Arthur Jensen proposed this notion, direct measures of neural-conduction velocity were not readily available. So Jensen primarily studied a proposed proxy for measuring neural-processing speed. The proxy was *choice reaction time*—the time it takes to select one answer from among several possibilities.

Consider a typical choice-reaction-time paradigm. The participant is seated in front of a set of lights on a board (Figure 13.3 ■). When one of the lights flashes, he or she extinguishes it by pressing as rapidly as possible a button beneath the correct light. The experimenter would then measure the participant's speed in performing this task.

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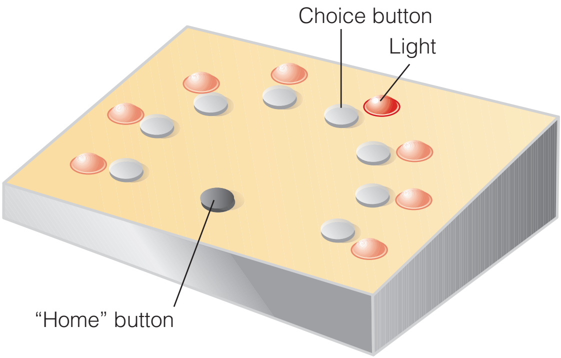

Figure 13.3 To measure choice reaction time, Jensen used an apparatus like the one shown here.

Source: Based on *Bias in Mental Testing* by Arthur R. Jensen. Copyright © 1980 by Arthur R. Jensen. All rights reserved.

Participants with higher IQs are faster than participants with lower IQs in their reaction time (RT; Jensen, 1982). In this particular version of the task, RT is defined as the time between when a light comes on and the finger leaves the home (central) button. In some studies, participants with higher IQs also showed a faster movement time (MT). MT is defined as the time between letting the finger leave the home button and hitting the button under the light. These findings may be due to increased central nerve-conduction velocity, although at present this proposal remains speculative (Reed & Jensen, 1991, 1993).

Research indicates choice RT may be influenced by extraneous factors, including the number of response alternatives and the visual-scanning requirements of Jensen's apparatus. In this case, RT as measured would not be a result of speed of reaction time alone (Bors, MacLeod, & Forrin, 1993). In particular, manipulating the number of buttons and the size of the visual angle of the display (how much of the visual field it consumes) can reduce the correlation between IQ and reaction time (Bors, MacLeod, & Forrin, 1993). Thus, the relation between reaction time and intelligence is unclear.

Lexical-Access Speed and Speed of Simultaneous Processing

Some investigations have focused on *lexical-access speed*—the speed with which we can retrieve information about words (e.g., letter names) stored in our long-term memories (Hunt, 1978). This speed can be measured with a letter-matching, reaction-time task first proposed by Posner and Mitchell in 1967 (Hunt, 1978).

Participants are shown pairs of letters, such as *A A*, *A a*, or *A b*. For each pair, they indicate whether the letters constitute a match in name (e.g., A a match in name of letter of the alphabet but A b do not). They also are given a simpler task. In it, they are asked to indicate whether the letters match physically (e.g., A A are physically identical, whereas A a are not). The variable of interest is the difference between their speed for the first set of tasks, involving name matching, and their speed for the second set, involving matching of physical characteristics. The difference in reaction time between the two kinds of tasks is said to provide a measure of speed of lexical access. This score is based on a *subtraction* of name-match minus physical-match reaction time. The subtraction controls for mere perceptual-processing time. Students with lower verbal ability take longer to gain access to lexical information than do students with higher verbal ability (Hunt, 1978).

Intelligence is also related to people's ability to divide their attention (Hunt & Lansman, 1982). For example, suppose that participants are asked to solve mathematical problems while listening for a tone and to press a button as soon as they hear it. We can expect that they both would solve the math problems effectively and respond quickly to

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hearing the tone. According to Hunt and Lansman, more intelligent people are better able to timeshare between two tasks and to perform both effectively.

In sum, process-timing theories attempt to account for differences in intelligence by appealing to differences in the speed of various forms of information processing. Inspection time, choice reaction time, and lexical access timing all have been found to correlate with measures of intelligence. These findings suggest that, on average, higher intelligence may be related to the speed of various information-processing abilities. More intelligent people encode information more rapidly into working memory. They access information in long-term memory more rapidly. And they respond more rapidly. Why would more rapid encoding, retrieval, and responding be associated with higher intelligence test scores? Do rapid information processors learn more?

Is there a link between age-related slowing of information processing and (1) initial encoding and recall of information and (2) long-term retention (Nettelbeck et al., 1996)? The relationship between inspection time and intelligence may not be related to learning. In particular, there is a difference between initial recall and actual long-term learning (Nettelbeck et al., 1996). Initial recall performance is mediated by processing speed. Older, slower participants showed deficits. Longer-term retention of new information, preserved in older participants, is mediated by cognitive processes other than speed of processing. These processes include rehearsal strategies. Thus, speed of information processing may influence initial performance on recall and inspection time tasks, but speed is not related to long-term learning. Perhaps faster information processing aids participants in performance aspects of intelligence test tasks, rather than contributing to actual learning and intelligence. Clearly, this area requires more research to determine how information-processing speed relates to intelligence.

Working Memory

Working memory is a critical component of intelligence. Indeed, some investigators have argued that intelligence may be little more than working memory (Conway et al., 2011; Kyllonen & Christal, 1990). In one study, participants read sets of passages and, after they had read the passages, tried to remember the last word of each passage (Daneman & Carpenter, 1983). Recall was highly correlated with verbal ability. In another study, participants performed a variety of working memory tasks. In one task, for example, the participants saw a set of simple arithmetic problems, each of which was followed by a word or a digit. An example would be "Is $(3 \times 5) - 6 = 7$? TABLE" (Turner & Engle, 1989; see also Hambrick, Kane, & Engle, 2005). The participants were given sets of two to six such problems and solved each one. After solving the problems in the set, they tried to recall the words that followed the problems. The number of words recalled was highly correlated with measured intelligence.

Working memory measurements may closely predict scores on tests of general ability (Colom et al., 2004; see also Conway et al. 2011). Other researchers have demonstrated a significant but smaller relationship between working memory and general intelligence (e.g., Ackerman, Beier, & Boyle, 2005). Thus, it appears that the ability to store and manipulate information in working memory may be an important aspect of intelligence. It is probably not all there is to intelligence, however.

Componential Theory and Complex Problem Solving

Cognitive approaches for studying information processing can be applied to more complex tasks, such as analogies, series problems (e.g., completing a numerical or figural series), and syllogisms (Sternberg, 1977, 1983, 1984; see Chapter 12). The idea is to take the kinds of tasks used on conventional intelligence tests and to isolate components of

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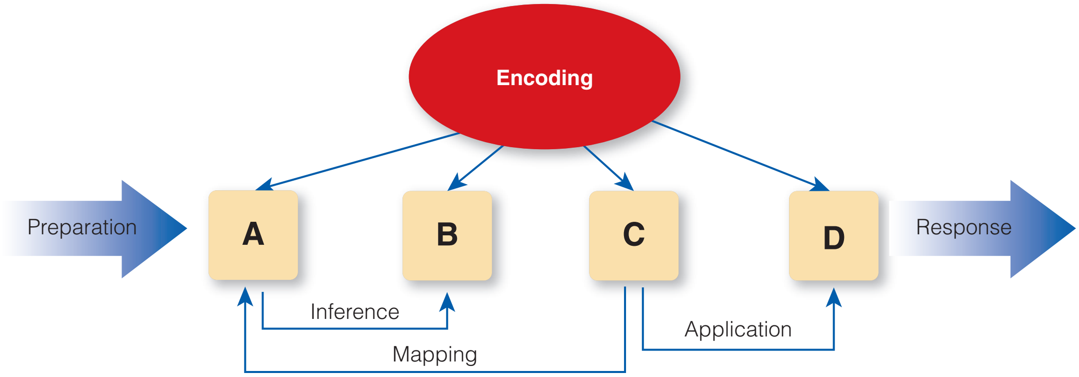
intelligence. *Components* are the mental processes used in performing these tasks, such as translating a sensory input into a mental representation, transforming one conceptual representation into another, or translating a conceptual representation into a motor output (Sternberg, 1982). Many investigators have elaborated on and expanded this basic approach (Lohman, 2005; Lohman & Lakin, 2011; Wenke, Frensch, & Funke, 2005; see Duggan & Garcia-Barrera, 2015).

Componential analysis breaks down people's reaction times and error rates on these tasks in terms of the processes that make up the tasks. This kind of analysis revealed that people may solve analogies and similar tasks by using several component processes. Among them are several processes. A first is encoding the terms of the problem. A second is inferring relations among at least some of the terms. A third is mapping the inferred relations to other terms, which would be presumed to show similar relations. And a fourth is applying the previously inferred relations to the new situations.

Consider the analogy LAWYER : CLIENT :: DOCTOR : (a. PATIENT, b. MEDICINE). To solve this analogy, you need to *encode* each term of the problem. This includes perceiving a term and retrieving information about it from memory. You then *infer* the relationship between lawyer and client. In particular, the former provides professional services to the latter. You then *map* the relationship in the first half of the analogy to the second half of the analogy. Here, you note that it will involve that same relationship. Finally, you *apply* that inferred relationship to generate the final term of the analogy. This leads to the appropriate response of PATIENT. Figure 13.4 ■ shows how componential analysis would be applied to an analogy problem, A is to B as C is to D, where D is the solution. Studying these components of information processing reveals more than measuring mental speed alone.

There are significant correlations between speed in executing these processes and performance on other, traditional intelligence tests. A more intriguing discovery, however, is that participants who score higher on traditional intelligence tests take longer to encode the terms of the problem than do less intelligent participants. But they make up for the extra time by taking less time to perform the remaining components of the task. In general, more intelligent participants take longer during *global planning*—encoding the problem and formulating a general strategy for attacking the problem (or set of problems). But they take less time for *local planning*—forming and implementing strategies for the details of the task (Sternberg, 1981).



■ **Figure 13.4** In the solution of an analogy problem, the problem solver must first encode the problem A is to B as C is to D. The problem solver then must infer the relationship between A and B. Next, the problem solver must map the relationship between A and B to the relationship between C and each of the possible solutions to the analogy. Finally, the problem solver must apply the relationship to choose which of the possible solutions is the correct solution to the problem.

Source: Sternberg, *Cognitive Psychology* 5e, Page 543, last column of Figure 13.4.

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in the lab of **IAN DEARY**

My "lab" consists of a number of attractive, late-Victorian offices in one wing of a building facing George Square gardens at the center of the University of Edinburgh, and human testing locations in the city's teaching hospitals. From these, I oversee the research on the Lothian Birth Cohorts of 1921 and 1936, and the Centre for Cognitive Ageing and Cognitive Epidemiology (CCACE).

The fundamental question the lab members are trying to answer is: Why do some people's brains and thinking skills age better than others? We also address an additional question: Why does cognitive ability from early life have a pronounced effect on people's health, illnesses, and survival later in life? The core of the day-to-day work is testing the members of the cohorts. The members of the Lothian Birth Cohort of 1936 are in their late seventies. They are special because they all took the same intelligence test as children and are being followed up on more than 60 years later. They will be tested individually by psychologists and nurses over the period 2015 to 2017. Therefore, the lab's activities are a mixture of intensive and long-term detailed cognitive testing, medical investigations, brain scanning, and genetic tests. My lab is rather unusual for psychology. It does contain some psychologists, but also epidemiologists, geneticists, and brain-imaging experts.

We have regular lab and Centre meetings to ensure that all the testing and day-to-day business is running on course. We also have journal clubs and scientific meetings to ensure, in addition, that the reporting of the work is on course.

Courtesy of Ian Deary

Ian Deary

With a set of cohorts that has such a wide variety of data, it is also important to have many senior and junior collaborators who bring additional expertise to our team. For example, we have many outside experts who help with aspects of genetics and brain imaging, and also on the many other areas into which the study delves.

In my lab, we have shown that around half of the variance in intelligence is stable from childhood to old age. We were the first lab to report substantial heritability of intelligence based on analysis of DNA in unrelated individuals. We found that the integrity of the brain's white matter accounts for about 10% of the variance in general cognitive ability in older people. We also have found that some factors that were thought to be protective against cognitive decline in older age actually are confounded with childhood intelligence; these include moderate alcohol consumption, coffee drinking, and engagement in sociocultural activities. In other words, what appeared to be the effect of, say, moderate alcohol consumption actually can be traced to the fact that people identified as more intelligent, even from childhood, tend to drink slightly more, although in moderation, and especially red wine. So prior intelligence, rather than moderate alcohol consumption, appears to be the deeper causal variable. We have found, however, some factors that actually might be helpful toward retaining cognitive capability in older age (although the individual effects are small)—for example, not smoking, being more physically fit, and speaking more than one language.

The advantage of spending more time on global planning is the increased likelihood that the overall strategy will be correct. Thus, when taking more time is advantageous, brighter people may take longer to do something than will less bright people. For example, the brighter person might spend more time researching and planning for writing a term paper but less time in the actual writing of it. This same differential in time allocation has been shown in other tasks as well. An example would be in solving physics problems (Larkin et al., 1980; see Sternberg, 1979, 1985a). That is, more intelligent people seem to spend more time planning for and encoding the problems they face. But they spend less time engaging in the other components of task performance. This may relate to the previously mentioned metacognitive attribute many include in their notions of intelligence.

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Researchers have studied information processing of people engaged in complex problem-solving situations. Examples include playing chess and performing logical derivations (Newell & Simon, 1972; Simon, 1976; see also Davidson & Sternberg, 2003). For example, a simple, brief task might require the participants first to view an arithmetic or geometric series. Then they must figure out the rule underlying the progression. And finally they must guess what numeral or geometric figure might come next. More complex tasks might include some of those mentioned in Chapter 11 (e.g., the water jugs problems; see Estes, 1982). Can performance on these or other tasks be analyzed at a biological level?

An Integrative Approach

An integrative approach would combine models of various kinds of cognitive functioning as bases for intelligence. In such an approach, four sources of individual differences in intelligence might be detected (Ackerman, 2005). These are (1) breadth of declarative knowledge, (2) breadth of procedural skills, (3) capacity of working memory, and (4) speed of processing. The advantage of this approach is that it does not try to localize individual differences in intelligence as coming from one source. Rather, multiple sources are involved.

Biological Bases of Intelligence

The human brain is the biological basis for human intelligence (Haier, 2011). Early studies, such as those of Karl Lashley, studied the brain to find biological indicators of intelligence and other aspects of mental processes. They were a resounding failure, despite great efforts. As tools for studying the brain have become more sophisticated, however, we are beginning to see the possibility of finding physiological indicators of intelligence. Some investigators believe that we will soon have clinically useful psychophysiological indices of intelligence (e.g., Matarazzo, 1992). But widely applicable indices will be much longer in coming. In the meantime, the biological studies we now have are largely correlational. They show statistical associations between biological and psychometric or other measures of intelligence. They do not establish causal relations.

One line of research looks at the relationship of brain volume to intelligence (see Haier, 2011; Jerison, 2000; Vernon et al., 2000; Witelson, Beresh, & Kiga, 2006). The evidence suggests that, for humans, there is a modest but significant statistical relationship between brain size and intelligence (Hair, 2011). It is difficult to know, however, what to make of this relationship. Greater brain size may cause greater intelligence, greater intelligence may cause greater brain size, or both may be dependent on some third factor. Moreover, it is probably at least as important how efficiently the brain is used than what its size is. For example, on average, men have larger brains than women. But women, on average, have better connections through the corpus callosum of the two hemispheres of the brain. So it is not clear which sex would be, on average, at an advantage. Probably neither would be. It is important to note that the relationship between brain size and intelligence does not hold across species (Hofman, 2015; Jerison, 2000). Rather, what holds seems to be a relationship between intelligence and brain size, relative to the rough general size of the organism.

For now, some of the current studies offer some appealing possibilities. For example, complex patterns of electrical activity in the brain, which are prompted by specific stimuli, appear to correlate with scores on IQ tests (Barrett & Eysenck, 1992). Several studies initially suggested that speed of conduction of neural impulses may correlate with intelligence, as measured by IQ tests (McGarry-Roberts, Stelmack, & Campbell, 1992; Vernon & Mori, 1992). A follow-up study, however, failed to find a strong relation

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between neural-conduction velocity and intelligence (Wickett & Vernon, 1994). In this study, conduction velocity was measured by neural-conduction speeds in a main nerve of the arm. Intelligence was measured by a Multidimensional Aptitude Battery. Surprisingly, neural-conduction velocity appears to be a more powerful predictor of IQ scores for men than for women. So sex differences may account for some of the differences in the data (Wickett & Vernon, 1994). Additional studies on both males and females are needed.

More recent work suggests it may be the flexibility of neural circuitry, rather than speed of conduction, that is key (Newman & Just, 2005). Hence, we would want to study not just speed but also neural circuitry. An alternative approach to studying the brain suggests that neural efficiency may be related to intelligence (Li et al., 2009; Neubauer & Fink, 2009). Such an approach is based on studies of how the brain metabolizes glucose (a simple sugar required for brain activity) during mental activities. (See Chapter 2 for more on positron emission tomography and other brain-imaging techniques.) Higher intelligence correlates with reduced levels of glucose metabolism during problem-solving tasks (Haier et al., 1992; Haier & Jung, 2007). That is, smarter brains consume less sugar and hence expend less effort than do less smart brains doing the same task. Furthermore, cerebral efficiency increases as a result of learning on a relatively complex task involving visuospatial manipulations, such as the computer game Tetris (Haier et al., 1992). As a result of practice, more intelligent participants not only show lower cerebral glucose metabolism overall but also show more specifically localized metabolism of glucose. In most areas of their brains, smarter participants show less glucose metabolism. But in selected areas of their brains, believed to be important to the task at hand, they show higher levels of glucose metabolism. Thus, more intelligent participants may have learned how to use their brains more efficiently. They carefully focus their thought processes on a given task.

Other research, however, suggests that the relationship between glucose metabolism and intelligence may be more complex (Haier et al., 1995; Larson et al., 1995). On the one hand, one study confirmed the earlier findings of increased glucose metabolism in less smart participants, in this case, participants who were mildly intellectually disabled (Haier et al., 1995). On the other hand, another study found, contrary to the earlier findings, that smarter participants had increased glucose metabolism relative to their average comparison group (Larson et al., 1995).

There was a problem with earlier studies. It was that the tasks participants received were not matched for difficulty level across groups of smart and average individuals. The study by Larson et al. used tasks that were matched to the ability levels of the smarter and average participants. They found that the smarter participants used more glucose. Moreover, the glucose metabolism was highest in the right hemisphere of the more intelligent participants performing the hard task. These results again suggest selectivity of brain areas. What could be driving the increases in glucose metabolism? Currently, the key factor appears to be subjective task difficulty. In earlier studies, smarter participants simply found the tasks to be too easy. Matching task difficulty to participants' abilities seems to indicate that smarter participants increase glucose metabolism when the task demands it. The preliminary findings in this area will need to be investigated further before any conclusive answers arise.

Some neuropsychological research suggests that performance on intelligence tests may not fully indicate a crucial aspect of intelligence. This is the ability to set goals, to plan how to meet them, and to execute those plans (Dempster, 1991). Specifically, people with lesions on the frontal lobe of the brain frequently perform quite well on standardized IQ tests. These tests require responses to questions within a highly structured situation. But they do not require much in the way of goal setting or planning. These tests frequently

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use what could be classified as crystallized intelligence. Damage to the posterior regions of the brain seems to have negative effects on measures of crystallized intelligence (Gray & Thompson, 2004; Kolb & Whishaw, 1996; Piercy, 1964). In patients with frontal lobe damage, impairments in fluid intelligence is observed (Duncan, Burgess, & Emslie, 1995; Gray, Chabris, & Braver, 2003; Gray & Thompson, 2004). This result should come as no surprise, given that the frontal lobes are involved in reasoning, decision making, and problem solving (see Chapters 10 and 11). Other research highlights the importance of the parietal regions for performance on general and fluid intelligence tasks (Colom et al., 2009; Lee et al., 2006). Intelligence involves the ability to learn from experience and to adapt to the surrounding environment (Greenwood, 2015). Thus, the ability to set goals and to design and implement plans cannot be ignored. An essential aspect of goal setting and planning is the ability to attend appropriately to relevant stimuli. Another related ability is that of ignoring or discounting irrelevant stimuli.

The discovered importance of the frontal and parietal regions in intelligence tasks has led to the development of an integrated theory of intelligence that highlights the importance of these areas. This theory, called the parietal-frontal integration theory (P-FIT), stresses the importance of interconnected brain regions in determining differences in intelligence. The regions this theory focuses on are the Brodmann areas, the prefrontal cortex, the inferior and superior parietal lobule, the anterior cingulate, and portions of the temporal and occipital lobes (Jung & Haier, 2007). P-FIT describes patterns of brain activity in people with different levels of intelligence; it cannot, however, explain what makes a person intelligent or what intelligence is.

We cannot realistically study a brain or its contents and processes in isolation without also considering the entire human being. We must consider the interactions of that human being with the entire environmental context within which the person acts intelligently. Hence, many researchers and theorists urge us to take a more contextual view of intelligence. Furthermore, some alternative views of intelligence attempt to broaden the definition of intelligence to be more inclusive of people's varied abilities.

Alternative Approaches to Intelligence

Cultural Context and Intelligence

According to **contextualism**, intelligence must be understood in its real-world context. The context of intelligence may be viewed at any level of analysis. It may be focused narrowly, as on the home and family environment, or it may be extended broadly, to entire cultures. For example, even cross-community differences have been correlated with differences in performance on intelligence tests. Such context-related differences include those of rural versus urban communities, low versus high proportions of teenagers to adults within communities, and low versus high socioeconomic status of communities (see Barnett et al., 2011; Coon, Carey, & Fulker, 1992). Contextualists have been intrigued particularly by the effects of cultural context on intelligence.

Contextualists consider intelligence to be inextricably linked to culture (Ang, Van Dyne, & Tan, 2011). They view intelligence as something that a culture creates to define the nature of adaptive performance in that culture. It further accounts for why some people perform better than others on the tasks that the culture happens to value (Sternberg, 2004). Theorists who endorse this model study just how intelligence relates to the external world in which the model is being applied and evaluated. In general, definitions and theories of intelligence will more effectively encompass cultural diversity by broadening in scope. Before exploring some of the contextual theories of intelligence, we will look at what prompted psychologists to believe that culture might play a role in how we define and assess intelligence.

Culture is defined here as "the set of attitudes, values, beliefs and behaviors shared by a group of people, communicated from one generation to the next via language or some other means of communication" (Barnouw, 1985, as cited in Matsumoto, 1994, p. 4). One reason to study culture and intelligence is that they are so inextricably interlinked. Indeed, Tomasello (2001) has argued that culture is what, in large part, separates human from animal intelligence (see also Mandalaywala, Fleener, & Maestripieri, 2015; Zentall, 2011, 2015). Humans have evolved as they have, he believes, in part because of their cultural adaptations, which in turn develop from their ability, even in infancy from about 9 months onward, to understand others as intentional agents.

Many research programs demonstrate the potential hazards of single-culture research. For example, Greenfield (1997) found that it means a different thing to take a test among Mayan children than it does among most children in the United States. The Mayan expectation is that collaboration is permissible and that it is rather unnatural *not* to collaborate. Such a finding is consistent with the work of Markus and Kitayama (1991), which suggests different cultural constructions of the self in individualistic versus collectivistic cultures. Indeed, Nisbett (2003) has found that some cultures, especially Asian ones, tend to be more dialectical in their thinking, whereas other cultures, such as European and North American ones, tend to be more linear. Similarly, people from Asian cultures tend to take a different viewpoint than Westerners when approaching a new object (Nisbett & Masuda, 2003). In general, people from Western cultures tend to process objects independently of the context, whereas people from many Eastern cultures process objects in conjunction with the surrounding context (Nisbett, 2004; Nisbett & Miyamoto, 2005). In fact, some evidence suggests that culture influences many cognitive processes, including intelligence (Lehman, Chiu, & Schaller, 2004). As a result, individuals in different cultures may construct concepts in quite different ways, rendering results of concept-formation or identification studies in a single culture suspect (Atran, 1999; Coley et al., 1999; Medin & Atran, 1999). Thus, groups may think about what appears superficially to be the same phenomenon—whether a concept or the taking of a test—differently. What appear to be differences in general intelligence may in fact be differences in cultural properties (Helms-Lorenz, Van de Vijver, & Poortinga, 2003). Helms-Lorenz et al. (2003) have argued that measured differences in intellectual performance may result from differences in cultural complexity; however, complexity of a culture is extremely hard to define, and what appears to be simple or complex from the point of view of one culture may appear different from the point of view of another.

People in different cultures may have quite different ideas of what it means to be smart. For example, one of the more interesting cross-cultural studies of intelligence was performed by Michael Cole and his colleagues (Cole et al., 1971). These investigators asked adult members of the Kpelle tribe in Africa to sort terms representing concepts. Consider what happens in Western culture when adults are given a sorting task on an intelligence test. More intelligent people typically will sort hierarchically. For example, they may sort names of different kinds of fish together. Then they place the word *fish* over that. They place the name *animal* over *fish* and over *birds,* and so on. Less intelligent people will typically sort functionally. They may sort *fish* with *eat,* for example. Why? Because we eat fish. Or they may sort *clothes* with *wear* because we wear clothes. The Kpelle sorted functionally. They did so even after investigators unsuccessfully tried to get the Kpelle spontaneously to sort hierarchically.

Finally, in desperation, one of the experimenters (Glick) asked a Kpelle to sort as a foolish person would sort. In response, the Kpelle quickly and easily sorted hierarchically.

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The Kpelle had been able to sort this way all along. They just had not done it because they viewed it as foolish. And they probably considered the questioners rather unintelligent for asking such stupid questions.

The Kpelle people are not the only ones who might question Western understandings of intelligence. In the Puluwat culture of the Pacific Ocean, for example, sailors navigate incredibly long distances. They do not use the navigational aids that sailors from technologically advanced countries would need to get from one place to another (Gladwin, 1970). Suppose Puluwat sailors were to devise intelligence tests for us and our fellow Americans. We and our compatriots might not seem very intelligent. Similarly, the highly skilled Puluwat sailors might not do well on American-crafted tests of intelligence. These and other observations have prompted quite a few theoreticians to recognize the importance of considering cultural context when intelligence is assessed.

One study provides an example a little closer to home regarding the effects of cultural differences on intelligence tests (Sarason & Doris, 1979). It tracked the IQs of an immigrant population: Italian Americans. Less than a century ago, first-generation Italian-American children showed a median IQ of 87 (low average; range 76–100). Their IQs were relatively low even when nonverbal measures were used and when so-called mainstream American attitudes were considered. Some social commentators and intelligence researchers of the day pointed to heredity and other nonenvironmental factors as the basis for the low IQs. Even in the 21st century, some commentators do the same for other minority groups (Herrnstein & Murray, 1994).

For example, a leading researcher of the day, Henry Goddard, pronounced that 79% of immigrant Italians were “feebleminded.” He also asserted that about 80% of immigrant Jews, Hungarians, and Russians were similarly unendowed (Eysenck & Kamin, 1981). Goddard (1917) also asserted that moral decadence was associated with this deficit in intelligence. He recommended that the intelligence tests he used be administered to all immigrants and that all those he deemed substandard would be excluded from entering the United States. But subsequent generations of Italian-American students who take IQ tests today show slightly above-average IQs (Ceci, 1991). Other immigrant groups that Goddard had denigrated have shown similar “amazing” increases. Even the most fervent hereditarians would be unlikely to attribute such remarkable gains in so few generations to heredity. Cultural assimilation, including integrated education, seems a much more plausible explanation.

The preceding arguments may make it clear why it is so difficult to come up with a test that everyone would consider **culture-fair**—equally appropriate and fair for members of all cultures. If members of different cultures have different ideas of what it means to be intelligent, then the very behaviors that may be considered intelligent in one culture may be considered unintelligent in another. Take, for example, the concept of mental quickness. In mainstream U.S. culture, quickness usually is associated with intelligence. To say someone is “quick” is to say that the person is intelligent. Indeed, most group tests of intelligence are strictly timed. Even on individual tests of intelligence, the test-giver times some responses of the test-taker. For example, one set of researchers observed a positive relationship between measures of quickness and scores on the Graduate Record Examinations (GREs; Powers & Kaufman, 2004). Many information-processing theorists and even psychophysiological theorists study intelligence as a function of mental speed.

In many cultures of the world, however, quickness is not at a premium. In these cultures, people may believe that more intelligent people do not rush into things. Even in our own culture, no one will view you as brilliant if you rush things that should not be rushed. For example, it generally is not smart to decide on a marital partner, a job, or a place to live in the 20 to 30 seconds you normally might have to solve an intelligence-test problem.

Because perfectly culture-fair intelligence tests do not exist, how should we consider context when assessing intelligence? Several researchers have suggested that providing culture-relevant tests is possible (e.g., Baltes, Dittmann-Kohli, & Dixon, 1984; Jenkins, 1979; Keating, 1984). **Culture-relevant tests** measure skills and knowledge that relate to the cultural experiences of the test-takers. Baltes, Dittmann-Kohli, and Dixon (1984), for example, have designed tests measuring skill in dealing with the pragmatic aspects of everyday life. Designing culture-relevant tests requires creativity and effort, but it is probably not impossible. For example, one study investigated memory abilities—one aspect of intelligence as our culture defines it—in our culture versus the Moroccan culture (Wagner, 1978). It found that the level of recall depended on the content that was being remembered. Culture-relevant content was remembered more effectively than nonrelevant content. For example, when compared with Westerners, Moroccan rug merchants were better able to recall complex visual patterns on black-and-white photos of Oriental rugs. Sometimes tests just are not designed to minimize the effects of cultural differences. In such cases, the key to culture-specific differences in memory may be the knowledge and use of metamemory strategies, rather than actual structural differences in memory (e.g., memory span and rates of forgetting; Wagner, 1978).

Andy Christiani/Alamy

Intricate patterns on Moroccan rugs were more easily remembered by Moroccan rug merchants than by Westerners. In contrast, Westerners more easily remembered information unfamiliar to Moroccan rug merchants.

Research has shown that rural Kenyan school children have substantial knowledge about natural herbal medicines. Western children, of course, would not be able to identify any of these medicines (Sternberg et al., 2001; Sternberg & Grigorenko, 1997). In short, making a test culturally relevant appears to involve much more than just removing specific linguistic barriers to understanding.

Similar context effects appear in children's and adults' performances on a variety of tasks. Three kinds of context affect performance (Ceci & Roazzi, 1994). The first is the social context. An example would be whether a task is considered masculine or feminine. The second is the mental context. An example would be whether a visuospatial task involves buying a home or burgling it. The third is the physical context. Here, an example would be whether a task is presented at the beach or in a laboratory. For example, 14-year-old boys performed poorly on a task when it was couched as a cupcake-baking task, but they performed well when it was framed as a battery-charging task (Ceci & Bronfenbrenner, 1985). Brazilian maids had no difficulty with proportional reasoning when hypothetically purchasing food, but they had great difficulty with it when hypothetically purchasing medicinal herbs (Schliemann & Magalhües, 1990). Brazilian children whose poverty had forced them to become street vendors showed no difficulty in performing complex arithmetic computations when selling things, but they had great difficulty performing similar calculations in a classroom (Carraher, Carraher, & Schliemann, 1985). Thus, test performance may be affected by the context in which the test terms are presented. The extent to which the context of performance resembles the context of learning of an intelligent action may partially determine the extent to which the behavior shows transfer from the first situation to the second (Barnett & Ceci, 2005).

In these studies, the investigators looked at the interaction of cognition and context. Several investigators have proposed theories that seek explicitly to examine this interaction within an integrated model of many aspects of intelligence. Such theories view intelligence as a complex system and are discussed in the next two sections.

Table 13.3 Gardner's Eight Intelligences

On which of Howard Gardner's eight intelligences do you show the greatest ability? In what contexts can you use your intelligences most effectively (after Gardner, 1999)?

Type of Intelligence	Tasks Reflecting this Type of Intelligence
Linguistic intelligence	Used in reading a book; writing a paper, a novel, or a poem; and understanding spoken words
Logical-mathematical intelligence	Used in solving math problems, in balancing a checkbook, in solving a mathematical proof, and in logical reasoning
Spatial intelligence	Used in getting from one place to another, in reading a map, and in packing suitcases in the trunk of a car so that they all fit into a compact space
Musical intelligence	Used in singing a song, composing a sonata, playing a trumpet, or even appreciating the structure of a piece of music
Bodily-kinesthetic intelligence	Used in dancing, playing basketball, running a mile, or throwing a javelin
Interpersonal intelligence	Used in relating to other people, such as when we try to understand another person's behavior, motives, or emotions
Intrapersonal intelligence	Used in understanding ourselves—the basis for understanding who we are, what makes us tick, and how we can change ourselves, given our existing constraints on our abilities and our interests
Naturalist intelligence	Used in understanding patterns in nature

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Gardner: Multiple Intelligences

Howard Gardner (1983, 1993b, 2006; Davis et al., 2011) proposed a **theory of multiple intelligences**, in which intelligence includes multiple independent constructs, not just a single, unitary construct. However, instead of speaking of multiple abilities that together constitute intelligence (e.g., Thurstone, 1938), this theory distinguishes eight distinct intelligences that are alleged to be relatively independent of each other (Table 13.3■). Each intelligence is a separate system of functioning, although these systems can interact to produce what we see as intelligent performance. Looking at Gardner's list of intelligences, you might want to evaluate your own intelligences, perhaps rank ordering your strengths in each.

In some respects, Gardner's theory sounds like a factorial one. It specifies several abilities that are construed to reflect intelligence of some sort. Gardner, however, views each ability as a separate intelligence, not just as a part of a single whole. Moreover, a crucial difference between Gardner's theory and factorial ones is in the sources of evidence Gardner used to identify the eight intelligences. Gardner used converging operations, gathering evidence from multiple sources and types of data. In particular, Gardner's theory uses eight "signs" as criteria for detecting the existence of a discrete kind of intelligence:

1. Potential isolation by brain damage. The destruction or sparing of a discrete area of the brain (e.g., areas linked to verbal aphasia) may destroy or spare a particular kind of intelligent behavior.
2. The existence of exceptional individuals (e.g., musical or mathematical prodigies). They demonstrate extraordinary ability (or deficit) in a particular kind of intelligent behavior.

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Courtesy of Dr. Howard Gardner

Howard Gardner.

3. An identifiable core operation or set of operations (e.g., detection of relationships among musical tones). It is essential to performance of a particular kind of intelligent behavior.
4. A distinctive developmental history leading from novice to master. It is accompanied by disparate levels of expert performance (i.e., varying degrees of expressing this type of intelligence).
5. A distinctive evolutionary history. Increases in intelligence plausibly may be associated with enhanced adaptation to the environment.
6. Supportive evidence from cognitive-experimental research. An example would be task-specific performance differences across discrete kinds of intelligence (e.g., visuospatial tasks versus verbal tasks). They would need to be accompanied by cross-task performance similarities within discrete kinds of intelligence (e.g., mental rotation of visuospatial imagery and recall memory of visuospatial images).
7. Supportive evidence from psychometric tests indicating discrete intelligences (e.g., differing performance on tests of visuospatial abilities versus on tests of linguistic abilities).
8. Susceptibility to encoding in a symbol system (e.g., language, math, musical notation) or in a culturally devised arena (e.g., dance, athletics, theater, engineering, or surgery as culturally devised expressions of bodily-kinesthetic intelligence). (Gardner, 1983, pp. 63–67)

Gardner does not dismiss entirely the use of psychometric tests. But the base of evidence used by Gardner does not rely on the factor analysis of various psychometric tests alone. In thinking about your own intelligences, how fully integrated do you believe them to be? How much do you perceive each type of intelligence as depending on any of the others?

Gardner's view of the mind is modular. Modularity theorists believe that different abilities—such as Gardner's intelligences—can be isolated as emanating from distinct portions or modules of the brain. Thus, a major task of existing and future research on intelligence is to isolate the portions of the brain responsible for each of the intelligences. Gardner has speculated as to at least some of these locales, but hard evidence for the existence of these separate intelligences has yet to be produced. Furthermore, some scientists question the strict modularity of Gardner's theory (Nettelbeck & Young, 1996). Consider the phenomenon of preserved specific cognitive functioning in autistic savants. Savants are people with severe social and cognitive deficits but with corresponding high ability in a narrow domain. They suggest that such preservation fails as evidence for modular intelligences. The narrow long-term memory and specific aptitudes of savants may not really be intelligent (Nettelbeck & Young, 1996). Thus, there may be reason to question the intelligence of inflexible modules.

Sternberg: The Triarchic Theory

Whereas Gardner emphasizes the separateness of the various aspects of intelligence, Robert Sternberg tends to emphasize the extent to which they work together in the triarchic theory of human intelligence (Sternberg, 1985a, 1996b, 2011). According to the **triarchic theory of human intelligence**, intelligence is composed of three aspects, dealing with the relation of intelligence (1) to the internal world of the person, (2) to experience, and (3) to the external world. Figure 13.5 ■ illustrates the parts of the theory and their interrelations.

How Intelligence Relates to the Internal World

The internal part of the theory emphasizes the processing of information. Information processing can be viewed in terms of three different kinds of components. First are metacomponents—higher-order executive processes (i.e., metacognition) used to plan,

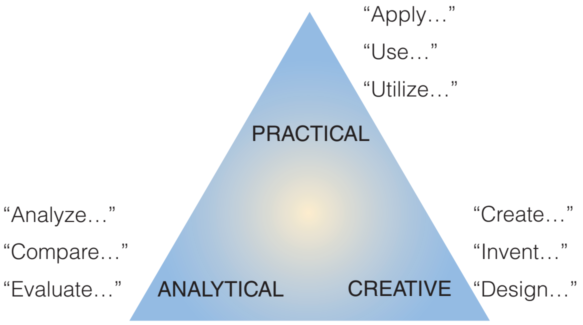

Figure 13.5 According to Robert Sternberg, intelligence comprises analytical, creative, and practical abilities. In analytical thinking, we try to solve familiar problems by using strategies that manipulate the elements of a problem or the relationships among the elements (e.g., comparing, analyzing); in creative thinking, we try to solve new kinds of problems that require us to think about the problem and its elements in a new way (e.g., inventing, designing); and in practical thinking, we try to solve problems that apply what we know to everyday contexts (e.g., applying, using).

monitor, and evaluate problem solving. Second are performance components—lower-order processes used to implement the commands of the metacomponents. And third are knowledge-acquisition components—the processes used for learning how to solve the problems in the first place. The components are highly interdependent.

Suppose that you were asked to write a term paper. You would use metacomponents for higher-order decisions. Thus, you would use them to decide on a topic, plan the paper, monitor the writing, and evaluate how well your finished product succeeds in accomplishing your goals for it. You would use knowledge-acquisition components for research to learn about the topic. You would use performance components for the actual writing. In practice, the three kinds of components do not function in isolation. Before actually writing the paper, you first would have to decide on a topic. Then you would have to do some research. Similarly, your plans for writing the paper might change as you gather new information. It may turn out that there is not enough information on particular aspects of the chosen topic. This scarcity of information may force you to shift your emphasis. Your plans also may change if particular aspects of the writing go more smoothly than others.

How Intelligence Relates to Experience

The theory also considers how prior experience may interact with all three kinds of information-processing components. That is, each of us faces tasks and situations with which we have varying levels of experience. They range from a completely novel task, with which we have no previous experience, to a completely familiar task, with which we have vast, extensive experience. As a task becomes increasingly familiar, many aspects of the task may become *automatic*. They require little conscious effort to determine what step to take next and how to implement that next step. A novel task makes demands on intelligence different from those of a task for which automatic procedures have been developed.

How Intelligence Relates to the External World

The triarchic theory also proposes that the various components of intelligence are applied to experience to serve three functions in real-world contexts:

- The first is adapting ourselves to our existing environments.
- The second is shaping our existing environments to create new environments.
- And the third is selecting new environments.

You use adaptation when you learn the ropes in a new environment and try to figure out how to succeed in it. For example, when you first started college, you probably tried to figure out the explicit and implicit rules of college life. You then try to use these rules to succeed in the new environment. You also shape your environment. For example, you may decide what courses to take and what activities to pursue. You even may try to shape the behavior of those around you, perhaps by starting a new campus organization or by running for student government. Finally, if you are unable either to adapt yourself or to shape your environment to suit you, you might consider selecting another environment. For example, you might transfer to a different college.

According to the triarchic theory, people may apply their intelligence to many different kinds of problems. For example, some people may be more intelligent in the face of abstract, academic problems. Others may be more intelligent in the face of concrete, practical problems. An intelligent person does not necessarily excel in all aspects of intelligence. Rather, intelligent people know their strengths and weaknesses. They find ways in which to capitalize on their strengths and either to compensate for or to correct their weaknesses. For example, a person who is strong in psychology but not in physics might choose as a physics project the creation of a physics aptitude test (which Sternberg did when he took physics). The point is to make the most of your strengths and to find ways to improve on or at least to live comfortably with your weaknesses.

We (Sternberg and colleagues) performed a comprehensive study testing the validity of the triarchic theory and its usefulness in improving performance. We predicted that matching students' instruction and assessment to their abilities would lead to improved performance (Sternberg et al., 1996; Sternberg et al., 1999). Students were selected for one of five ability patterns: high only in analytical ability, high only in creative ability, high only in practical ability, high in all three abilities, or not high in any of the three abilities. Then students were assigned at random to one of four instructional groups. They emphasized either memory-based, analytical, creative, or practical learning. Then the memory-based, analytical, creative, and practical achievement of all students was assessed. We found that students who were placed in an instructional condition that matched their strength in terms of pattern of ability outperformed students who were mismatched. Thus, the prediction of the experiment was confirmed. For example, a high-analytical student being placed in an instructional condition that emphasized analytical thinking outperformed a high-analytical student being placed in an instructional condition that emphasized practical thinking.

Teaching students to use all of their analytic, creative, and practical abilities has resulted in improved school achievement for some students, whatever their ability pattern (Grigorenko, Jarvin, & Sternberg, 2002; Sternberg & Grigorenko, 2004; Sternberg, Torff, & Grigorenko, 1998), but not for all students (Sternberg et al., 2014).

One attempt to broaden the assessment can be seen through the Rainbow Project and related studies (Sternberg, 2010). In the Rainbow Project, students completed the SAT and additional assessments. These additional assessments measured creative and practical abilities as well as of analytical abilities (Sternberg & the Rainbow Project Collaborators, 2006). The addition of these supplemental assessments resulted in superior prediction of college grade point average (GPA) as compared with scores on the SAT and high school GPA. In fact, the new tests doubled the prediction of first-year college GPA obtained just by the SAT. Moreover, the new assessments substantially reduced differences in scores among members of diverse ethnic groups.

Thus far, we have described various models of human intelligence. These models do not, in themselves, state whether intelligence can be taught or improved through instruction. A number of investigators have addressed this issue, however. Can intelligence actually be modified with instruction, and if so, how? What strategies are effective, and which ones, less so? Consider the answers.

practical applications of **COGNITIVE PSYCHOLOGY**

Intelligence and Culture

Robert L. Williams developed a test he called the BITCH Test (Black Intelligence Test of Cultural Homogeneity). Many “standard” intelligence tests rely heavily on vocabulary (e.g., the Shipley Test, a major section on the Wechsler intelligence tests). Williams scored very poorly on an intelligence test when he was in high school, so he was advised not to go to college but to develop trade skills. Because Williams knew he had “street smarts,” he ignored this advice, went to college, and eventually earned his PhD. To demonstrate that knowledge of vocabulary does not capture all of what goes into intelligence, Williams’ BITCH test asked people to define various “black” terms of the time, such as “alley apple,” “deuce-and-a-quarter,” and “Mother’s Day.” Not surprisingly, most blacks did better on this test than their white counterparts. The items on the test were culturally relevant to most blacks at the time (many of the terms are outdated now), and they were culturally irrelevant to most whites.

Improving Intelligence: Effective, Ineffective, and Questionable Strategies

Human intelligence is malleable—up to a point. It can be shaped and even increased through various kinds of interventions (Detterman & Sternberg, 1982; Grotzer & Perkins, 2000; Jaeggi et al., 2008; Sternberg et al., 1997). The malleability of intelligence is not genetically based (Sternberg, 1997). An attribute, such as height, can be partly or even largely genetically based and yet can be environmentally malleable.

Abundant evidence indicates that a variety of factors can affect intellectual skills. One factor is people’s environments (Ceci, Nightingale, & Baker, 1992; Reed, 1993; Sternberg & Wagner, 1994). Another is their motivation (Collier, 1994; Sternberg & Ruzgis, 1994). A third is their training (Feuerstein, 1980; Sternberg, 1987b). Although environmental factors matter, heredity certainly plays a role in individual differences in intelligence (Loehlin, Horn, & Willerman, 1997; Plomin, 1997; Plomin et al., 2012), as does the environment (Sternberg & Grigorenko, 1999; Wahlsten & Gottlieb, 1997). Genetic inheritance may set some kind of upper limit on how intelligent a person may become. We now know, however, that for any attribute that is partly genetic, there is a *reaction range*. This is the range of broad limits of possibilities in which an attribute can be expressed in various ways. Thus, each person’s intelligence can be developed further within this broad range of potential intelligence (Grigorenko, 2000). We have no reason to believe that people now reach their upper limits in the development of their intellectual skills. To the contrary, the evidence suggests that we can do quite a bit to help people become more intelligent (for further discussion of these issues, see Mayer, 2000a; Sternberg, 1995; see also Neisser et al., 1996).

Improving Children’s Intelligence

The Head Start program was initiated in the 1960s to provide preschoolers with an edge on intellectual abilities and accomplishments when they started school. Long-term follow-up studies have indicated that by mid-adolescence, children who participated in the program were more than a grade ahead of matched controls who did not receive the program (Lazar & Darlington, 1982; Zigler & Berman, 1983). The children in the program also scored higher on a variety of tests of scholastic achievement. They were also less likely to need remedial attention. And they were less likely to show behavioral problems. Although such measures are not truly measures of intelligence, they show strong positive correlations with intelligence tests.

An alternative to intellectual enrichment outside the home may be to provide an enriched home environment. A particularly successful project has been the Abecedarian Project. It showed that the cognitive skills and achievements of lower socioeconomic status children could be increased through carefully planned and executed interventions (Ramey & Ramey, 2000). For instance, children who took part in the Abecedarian program completed more years of postsecondary education than did their nonexperimental peers (Campbell et al., 2002). In another study utilizing portions of the Abecedarian program with low-birth-weight children, early intervention also produced improvements in a number of skills, including ones measured in math and reading tasks (McCormick et al., 2006).

INVESTIGATING COGNITIVE PSYCHOLOGY

Teaching Intelligence

A number of training programs have shown some success. One such program is Reuven Feuerstein's (1980) Instrumental Enrichment program. It involves training in a variety of abstract-reasoning skills. It appears to be particularly effective for improving the skills of performers who have mental disabilities. Another program, the Odyssey program (see Adams, 1986), was shown to be effective in raising the intellectual performance of Venezuelan children of junior high school age. The Philosophy for Children program (Lipman, Sharp, & Oscanyan, 1980) also was shown to teach logical-thinking skills to children throughout the primary and secondary levels of schooling. Aspects of the Intelligence Applied program (Sternberg, 1986; Sternberg & Grigorenko, 2002a; Sternberg, Kaufman, & Grigorenko, 2008) for teaching intellectual skills have been shown to be effective. This program can improve both insight skills (Davidson & Sternberg, 1984) and the ability to learn meanings of words from context, a primary means for acquiring new vocabulary (Sternberg, 1987a). Practical intelligence also can be taught (Gardner et al., 1994; Sternberg, Okagaki, & Jackson, 1990).

Several factors in the early (preschool) home environment appear to be correlated with high IQ scores (Bradley & Caldwell, 1984). They are emotional and verbal responsivity of the primary caregiver and the caregiver's involvement with the child, avoidance of restriction and punishment, organization of the physical environment and activity schedule, provision of appropriate play materials, and opportunities for variety in daily stimulation. Furthermore, Bradley and Caldwell found that these factors more effectively predicted IQ scores than did socioeconomic status or family-structure variables. It should be noted, however, that the Bradley–Caldwell study is correlational. It therefore cannot be interpreted as indicating causality. Furthermore, their study pertained to preschool children. Children's IQ scores do not begin to predict adult IQ scores well until the age of 4. Moreover, before the age of 7, the scores are not stable (Bloom, 1964). Other work has suggested that factors such as maternal social support and interactive behavior may play a key role in the instability of scores on tests of intellectual ability between the ages of 2 and 8 (Pianta & Egeland, 1994).

The Bradley and Caldwell data should not be taken to indicate that demographic variables have little effect on IQ scores. On the contrary, throughout history and across

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cultures, many groups of people have been assigned pariah status as inferior members of the social order. Across cultures, these disadvantaged groups (e.g., native Maoris versus European New Zealanders) have shown differences in tests of intelligence and aptitude (Steele, 1990; Zeidner, 1990). Such was the case of the Burakumin tanners in Japan. In 1871, they were granted emancipation but not full acceptance into Japanese society. On the one hand, they show poor performance and underprivileged status in Japan. On the other hand, those who immigrate to America—and are treated like other Japanese immigrants—perform on IQ tests and in school achievement at a level comparable to that of their fellow Japanese Americans (Ogbu, 1986).

Similar positive effects of integration were shown on the other side of the world. In Israel, the children of European Jews score much higher on IQ tests than do children of Arabic Jews. The exception is when the children are reared on kibbutzim. Here, the children of all national ancestries are raised by specially trained caregivers, in a dwelling separate from their parents. When these children shared the same child-rearing environments, there were no national-ancestry–related differences in IQ (Smilansky, 1974).

Blackwell, Trzesniewski, and Dweck (2007) examined junior high school students and their beliefs about the nature of intelligence. The belief that intelligence is malleable predicted an improvement in mathematics achievement over the following 2 years. However, the students who believed that intelligence is fixed showed no significant change over this same time frame. In a second study, students whose math grades were declining were taught about the malleability of intelligence. The grades of students who received this training stopped declining. Furthermore, the students became more motivated in the classroom. However, the students who did not receive this training continued to show declines in their grades. These findings indicate that intelligence not only is malleable but also is greatly affected by our expectations.

Development of Intelligence in Adults

Intelligence develops with age (Anderson, 2005). Do scores on cognitive-ability tests continue to increase indefinitely? The available data suggest that they may not (Berg, 2000). Although crystallized intelligence is higher, on average, for older adults than for younger adults, fluid intelligence is higher, on average, for younger adults than for older ones (Horn & Cattell, 1966). At the college level, then, both fluid and crystallized abilities are increasing. Later in life, however, the picture often changes.

For example, the performance of older adults on many information-processing tasks appears to be slower, particularly on complex tasks (Cerella, 1990, 1991; Hertzog, 2011; Schaie, 1989). In general, crystallized cognitive abilities seem to increase throughout the life span, whereas fluid cognitive abilities seem to increase up until the 20s, 30s, or possibly 40s and slowly decrease thereafter. The preservation of crystallized abilities suggests that long-term memory and the structure and organization of knowledge representation are preserved across the life span (Salthouse, 2005, 2009). Moreover, many adults find ways of compensating for later deficits in skills so that their actual performance is unaffected. For example, older typists may type less quickly but look further ahead in their typing to compensate for the loss of processing speed (Salthouse, 1996). Or if they are forgetful, they may write notes to themselves more often than they did when they were younger.

Although psychometric researchers disagree about the age when fluid intelligence starts to decline, many researchers agree that eventually some decline does indeed occur, on average. The rate and extent of decline varies widely across people. Some cognitive abilities also seem to decline under some circumstances but not others, on average. For example, effectiveness of performance on some problem-solving tasks appears to show age-related decline (Denny, 1980; Hertzog, 2011), although even brief training appears

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to improve scores on problem-solving tasks for older adults (Rosenzweig & Bennett, 1996; Willis, 1985). Other research implicates declines in executive functioning as a reason for decreased performance on intelligence tests (Taconnat et al., 2007).

Not all cognitive abilities decline, however. For example, one book (Cerella et al., 1993) devotes 20 chapters to describing studies showing little or no intellectual decline in various areas of cognition, including object and word perception, language comprehension, and problem solving. Some researchers have found that some kinds of learning abilities seem to increase (e.g., Schaie & Willis, 1986), and others have found that the ability to learn and remember meaningful skills and information shows little decline (Graf, 1990; Labouvie-Vief & Schell, 1982; Perlmutter, 1983b). Also, even in a single domain, such as memory, decreases in one kind of performance may not imply decreases in another. For example, although short-term memory performance seems to decline (Hertzog, 2011; Hultsch & Dixon, 1990), long-term memory (Bahrick, Bahrick, & Wittlinger, 1975) and recognition memory (Schonfield & Robertson, 1966) remain quite good.

Some researchers (e.g., Schaie, 1996, 2005, 2009) even question much of the evidence for intellectual decline. For one thing, our views of memory and aging may be confounded by reports of pathological changes that occur in some older adults. Such changes do not result from general intellectual decline but rather from specific neurophysiological disorders. These neurophysiological disorders, such as Alzheimer's disease, are fairly uncommon even among the most elderly. Preventive screening tools for Alzheimer's disease, which capitalize on differences in typical aging adult abilities, currently are being investigated with mixed success (Mirmiran, von Someren, & Swaab, 1996). Cognitive abilities seem to decline most in the last 10 years before death. The amount of decline occurring in these later years is, in part, predicted by intelligence test scores early in life (Bourne et al., 2007).

Another qualification on findings of decline in older age is the frequent use of cross-sectional research designs, which involve testing different cohorts (generations) of individuals at the same time. Such designs tend to overestimate the extent of decline of cognitive abilities. For unknown reasons, more recent generations of individuals show higher cognitive abilities—at least as measured by IQ (Flynn, 1984, 1987, 2015)—than do earlier generations. Consequently, the lower IQs of the older individuals may be a generational effect rather than an aging effect. Indeed, longitudinal research designs, which test the same individuals repeatedly over an extended period, suggest less decline in mental abilities with age. These studies, however, may underestimate the extent of decline resulting from selective dropout. The less-able participants drop out of the study over the years, perhaps because they find the taking of the cognitive tests to be discouraging or even humiliating.

Although the debate about intellectual decline with age continues, positions have converged somewhat. For instance, there is a consensus (Cerella, 1990, 1991; Hertzog, 2011; Kliegl, Mayr, & Krampe, 1994; Salthouse, 1996) that some slowing of the rate of cognitive processing occurs across the span of adulthood, and the evidence of slowing remains even when the experimental methodology and analyses rule out the disproportionate representation of demented adults among the elderly (Salthouse, Kausler, & Saults, 1990). Among the general factors that have been suggested as contributing to age-related slowing of cognitive processing have been a generalized decline in central nervous system functioning (Cerella, 1991), a decline in working-memory capacity (Salthouse, 1993, 2009), a decline in attentional resources (see Horn & Hofer, 1992), and a decline in the functioning of the frontal lobes (Bugg et al., 2006).

Slowed processing might lead to cognitive deficits through two speed-related issues in cognitive functioning—limited time and simultaneity (Salthouse, 1996, 2009). Slowed processing may prevent certain operations from being computed. Such operations may need to occur within a limited amount of time. The operations may need to overlap because of storage limitations. For example, auditory memory exhibits rapid decay, leading to the necessity for rapid classification of auditory signals. Slowing of upper-level processing can result in incomplete or inaccurate processing of auditory signals. Given the semiparallel nature of much of cognitive processing along with the nature of synaptic transmission, that speed would be an issue is not surprising—such processing is time dependent.

In addition to these general factors, many cognitive-developmental psychologists have suggested that specific factors also affect age-related changes in cognitive processing. The specific factors differentially may affect various cognitive tasks. For example, specific factors include greater slowing of higher-order cognitive processes than of sensory-motor processes (Cerella, 1985). They also include differential slowing of high- versus low-complexity tasks (Kliegl, Mayr, & Krampe, 1994). A further cognitive factor is greater slowing for tasks requiring coordinative complexity (requiring simultaneous processing of multiple stimuli) than for sequential complexity (requiring sequential processing of multiple stimuli; Mayr & Kliegl, 1993). A final factor is greater age-related decline in processes of information retrieval than in processes of encoding (see Salthouse, 1992). In addition, priming effects and tasks requiring implicit memory seem to show little or no evidence of decline (Mitchell & Bruss, 2003). But tasks involving explicit memory do show age-related decline.

Older adults develop practical strategies to retain relatively high levels of functioning (Berg et al., 1998; Berg, Meegan, & Deviney, 1998; Hertzog, 2009; Sternberg, Grigorenko, & Oh, 2001). They also can draw on practical knowledge that younger people may not have (Berg, 2000; Colonia-Willner, 1998; Torff & Sternberg, 2001).

Although the evidence regarding age-related differences in the selection of cognitive strategies is mixed, there appear to be no age-related differences in self-monitoring of cognitive processes (see Salthouse, 1992). So it would appear that older adults may be able to effectively utilize information regarding how to enhance their cognitive performance. Also, when task performance is based more on accuracy than on speed, older adults may at least partly compensate for speed deficits with increased carefulness and persistence (see Horn & Hofer, 1992). Furthermore, at all times throughout the life span, there is considerable *plasticity*—modifiability—of abilities (Baltes, 1997; Baltes & Willis, 1979; Garlick, 2002; Mirmiran, von Someren, & Swaab, 1996; Rosenzweig & Bennett, 1996). None of us is stuck at a particular level of performance. Each of us can improve.

Some psychologists have become particularly interested in the development of wisdom in adulthood (see Sternberg, 1990; Sternberg & Jordan, 2005). Most theorists have argued that wisdom increases with age, although there are exceptions (Meacham, 1990). Psychologists' definitions of wisdom have been diverse. Some (Baltes et al., 1995; Baltes & Smith, 1990; Baltes & Staudinger, 2000; Staudinger & Glueck, 2011) define *wisdom* as exceptional insight into human development and life matters, including exceptionally good judgment and advice and commentary about difficult life problems. Furthermore, wisdom can be seen as reflecting a positive gain in culture-based cognitive pragmatics (meaningful uses of cognitive skills) in the face of the more physiologically controlled losses in cognitive mechanics (Baltes, 1993). Other research has found six factors in people's conceptions of wisdom. They are reasoning ability, sagacity (shrewdness), learning from ideas and from the environment, judgment, expeditious use of information, and perspicacity (intensely keen awareness, perception, and insight) (Sternberg, 1985b). In wisdom, to know what you do not know is also important (Meacham, 1983, 1990). Sternberg (2013) has characterized wisdom as involving the use of one's knowledge and abilities to help attain a common good, over the long term as well as the short term,

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through the infusion of positive ethical values. Whatever the definition of wisdom, it is clear that wisdom can help people adapt to their environments and make the world better not just for themselves but for others as well.

Artificial Intelligence: Computer Simulations

Can a Computer Program Be "Intelligent"?

Much of the early information-processing research centered on work based on computer simulations of human intelligence as well as computer systems that use optimal methods to solve tasks. Programs of both kinds can be classified as examples of *artificial intelligence* (AI), or intelligence in symbol-processing systems such as computers (see Schank & Towle, 2000). Computers cannot actually think. They must be programmed to behave as though they are thinking. That is, they must be programmed to simulate cognitive processes. In this way, they give us insight into the details of how people process information cognitively. Essentially, computers are just pieces of hardware—physical components of equipment—that respond to instructions. Other kinds of hardware (other pieces of equipment) also respond to instructions. For example, if you can figure out how to give the instructions, a DVR (digital video recorder) will respond to your instructions and will do what you tell it to do.

What makes computers so interesting to researchers is that they can be given highly complex instructions, known as computer programs or even more commonly as software. Programs tell the computer how to respond to new information.

Before we consider any intelligent programs, we need to consider seriously the issue of what, if anything, would lead us to describe a computer program as being "intelligent."

The Turing Test

Alan Turing (1963) probably made the first attempt to determine whether a computer program can be intelligent, based on ideas he first presented in 1950. Specifically, Turing devised a test by which a human could assess the intelligence of a respondent (see Chapter 1). The basic idea behind the Turing Test is whether an observer can distinguish the performance of a computer from that of a human. For the test to work, everyone must agree that the human is intelligent in at least some degree. In the specific form proposed by Turing, the test is conducted with a computer, a human respondent, and an interrogator. The interrogator has two different "conversations" with an interactive computer program. The goal of the interrogator is to figure out which of two parties is a person communicating through the computer and which is the computer itself. The interrogator can ask the two parties any questions at all. The computer, however, will try to fool the interrogator into believing that it is human. The human, in contrast, will try to show the interrogator that he or she truly is human. The computer passes the Turing Test if an interrogator is unable to distinguish the computer from the human.

The test of indistinguishability of computer from human is commonly used in assessing the intelligence of a computer program. The test is not usually performed in quite the way described by Turing. For example, outputs of some kind generated by a computer might be scanned and assessed for their comparability to human performance. In some cases, human data from a problem-solving task are compared with computer-generated data. The degree of relation between them is then evaluated. For example, suppose a computer solves number-series problems such as 1, 4, 9, 16, . . . (where each number is the next larger perfect square). The response times and error patterns of the computer can be compared with those of human participants who have solved the same problems (Kotovsky & Simon, 1973; Simon & Kotovsky, 1963). Of course, the response times of the computer are typically much faster than those of humans, but the researchers are less interested in overall reaction times than in patterns of reaction times. In other words, what matters is not whether computers take more or less time on each problem than do humans. Rather, it is whether the problems that take the computer relatively longer to solve also take human participants relatively longer.

Sometimes, the goal of a computer model is not to match human performance but to exceed it. In this case, maximum AI, rather than simulation of human intelligence, is the goal of the program. The criterion of whether computer performance matches that of humans is no longer relevant. Instead, the criterion of interest is that of how well the computer can perform the task assigned to it. Computer programs that play chess, for example, typically play in a way that emphasizes "brute force." The programs evaluate extremely large numbers of possible moves. Many of them are moves humans would never even consider evaluating (Berliner, 1969; Bernstein, 1958). Using brute force, the IBM program "Deep Blue" beat world champion Gary Kasparov in a 1997 chess match. The same brute-force method is used in programs that play checkers (Samuel, 1963). These programs generally are evaluated in terms of how well they can beat each other or, even more important, human contenders playing against them.

Applications of Artificial Intelligence

An application of AI can be seen in a competition sponsored by the Defense Advanced Research Projects Agency (DARPA). The program, originally called the DARPA Grand Challenge, requires groups to develop an automated vehicle (DARPA, 2007). Early versions of this project have had some success and have led to more challenging versions each year that it had been conducted. The most recent version of this challenge is the DARPA Urban Challenge, which requires the vehicle to independently perform in an urban environment including traffic (DARPA, 2007). This challenge does not permit drivers or control via a remote. As a result, these vehicles must integrate AI capable of assessing and reacting to new environments.

Another application of AI can be seen in the Mars rovers. The designers integrate AI into these rovers, enabling them to make (some) mission decisions and be self-reliant (Bluck, 2004). The application of AI to these projects has led to independent machines capable of performing complex operations in variable environments. Clearly, these applications are major improvements over the original attempts at AI.

Intelligence versus the Appearance of Intelligence

A philosopher has raised an objection to the basic idea that computers can be considered truly intelligent (Searle, 1980). To make his objection, he uses what is known as the "Chinese Room" problem. Imagine that Searle, the philosopher, is locked in a room. He is given a large batch of Chinese writing to translate. He knows no Chinese at all. Suppose that, in addition to the Chinese writing, Searle is given a second batch of Chinese script. He also receives a set of rules for translating the Chinese into English. Next, Searle is given a third batch. It gives him a set of rules for formulating responses to questions that were raised in the first batch of Chinese writing. Searle then responds to the original batch of writing with a response that makes sense and is in perfect Chinese. Presumably, over time, Searle could become extremely good at manipulating the rules. His responses would be every bit as good as those of a native Chinese speaker who understood exactly

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practical applications of COGNITIVE PSYCHOLOGY

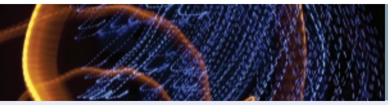
Cognitive Styles

What is your dominant cognitive style? Defining your preferred way of interacting with the environment could help you perform better in school or on the job. The "Thinking about Thinking" section at the end of each of the chapters in this text was designed to appeal to different cognitive styles to more meaningfully integrate the information in each chapter. Which questions were more appealing to you or helped you most? Analytical questions asked you to compare, analyze, or evaluate ideas; creative questions asked you to design or create; and practical questions asked you to apply information to other situations. Try to apply your knowledge in all three ways for the most effective and flexible use.

what was being asked. In fact, however, Searle still knows no Chinese at all. He is simply following a set of rules.

According to Searle, programs that seem to understand various kinds of inputs and to respond in a seemingly intelligent way are like Searle in the Chinese room. The computers understand the input being given to them no better than Searle understands Chinese. They are simply operating according to a set of preprogrammed rules. Searle's notion is that the computer does not really see and understand the connections between input and output. Rather, it uses preestablished connections that make it seem intelligent on the surface. To Searle, these programs do not demonstrate AI. They only appear to show intelligence.

Predictably, AI researchers have not competed with each other to be the first to accept Searle's argument. They generally have not been eager to acknowledge any folly in their attempts to model AI. A number of researchers have offered responses to Searle's charge that the computer is not anything like what it is cracked up to be. One scientist, for example, argued that Searle's use of the rule systems in the second and third batches of input is, in fact, intelligent (Abelson, 1980). He further argued that children learning a language also at first apply rules rather blindly. Only later do they come to understand the rules and how they are being used. Others argue that the system as a whole (comprising Searle as well as the set of instructions) does indeed exhibit understanding. In addition, some computer programs even have shown an ability to simulate at least a modest degree of skill development and knowledge acquisition. Nevertheless, existing computer programs do not begin to approach our human ability to enhance our own intelligence.



Key Themes

This chapter addresses several of the themes described in Chapter 1.

Nature versus nurture. This theme has played a major part in intelligence research since the 19th century. Investigators are in general agreement that nature plays a role. Intelligence is partially heritable. The estimates of heritability actually increase with age. The older you are, the more nature plays a role and the less nurture plays a role. This may be because of differential effects of early rearing environments that start to wear off. But the kind of environment an individual has affects the extent to which people can utilize and make the most of their genetic potential. Moreover, research shows that environment can affect biology. The brain changes as a result of learning experiences.

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Causal inference versus ecological validity. Some studies of intelligence have been done in the laboratory. Others, especially studies of practical intelligence and cultural studies of intelligence, more often have been done in the field. For example, studies of practical intelligence in rural Kenya simply cannot be done in a highly controlled setting. Both kinds of studies enhance our knowledge of intelligence. They complement each other.

Basic versus applied research. In the 20th century, much of the early research done on intelligence was applied. It was designed to create, standardize, and validate intelligence tests. But later in the 20th century, researchers started to realize that they had very little idea of the cognitive processes that contribute to performance on the tests. So more basic research ensued in which investigators tried to understand these cognitive processes. The research suggested that the tests gave useful information. But other kinds of tests also emerged as useful for understanding human intelligence and individual differences in it.

SUMMARY

1. **What are the key issues in intelligence research? How do different researchers and theorists respond to those issues?** An early issue in the study of intelligence centered on how to measure intelligence. Francis Galton and his followers emphasized psychophysical acuity. Binet and his followers emphasized judgment. Two common themes that run through the definitions of intelligence proposed by many experts are the capacity to learn from experience and the ability to adapt to the environment. In addition, the importance of metacognition and of cultural context increasingly are recognized by researchers and theorists of intelligence. Nonetheless, psychologists often disagree regarding the relative importance of context (nurture) versus inheritance (nature) in determining intelligence. Also, different researchers disagree regarding whether to focus on studying the structures of intelligence (e.g., Spearman, Thurstone, Cattell) or the processes of intelligence (e.g., Hunt, Jensen, Simon). Some researchers (e.g., Gardner, Sternberg) also have focused on trying to integrate the various approaches to intelligence into comprehensive systems models of intelligence. One approach to intelligence is to understand it in terms of factor analysis. This is a statistical technique that seeks to identify latent sources of individual differences in performance on tests. There are several principal factor-analytic models of the mind.

   One is Spearman's "g" factor. Another is the primary mental abilities model of Thurstone. And a third comprises the hierarchical models of Cattell, of Vernon, and of Carroll, among others.
2. **What are some information-processing approaches to intelligence?** An alternative approach to intelligence is to understand it in terms of information processing. Information-processing theorists have sought to understand intelligence in terms of a number of constructs and tasks. They include inspection time, choice reaction time, speed of lexical access, the ability to divide attention successfully, the components of reasoning and problem solving, and complex problem solving that can be simulated via computers. A related approach is the biological model. It uses increasingly sophisticated means of viewing the brain while the brain is engaged in intelligent behaviors. Preliminary findings suggest that speed of neural conduction may play a role in intelligence. Particularly intriguing are findings suggesting that neural efficiency and specialization of cerebral function may be influential in intelligent cognitive processing.

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3. **What are some alternative views of intelligence?** Another main approach to understanding intelligence (based on an anthropological model) is a contextual approach. According to this approach, intelligence is viewed as wholly or partly determined by cultural values. Contextual theorists differ in the extent to which they believe that the meaning of intelligence differs from one culture to another. What is considered to be intelligent behavior is, to some extent, culturally relative. The same behavior that is considered to be intelligent in one culture may be considered unintelligent in another culture. To create a test of intelligence that is culture-fair—that is, equally fair for members of different cultures—is difficult, and perhaps impossible. Members of different cultures have different conceptions of what constitutes intelligent behavior.

   Systems models of intelligence seek to go beyond cultural content. Gardner's theory of multiple intelligences specifies that intelligence is not a unitary construct. Rather, there are multiple intelligences, each relatively independent of the others. Sternberg's triarchic theory of human intelligence conceives of intelligence in terms of information-processing components. They are applied to experience to serve the functions of adaptation to the environment, shaping of the environment, and selection of new environments.
4. **Can intelligence be improved, and if so, how?** Intellectual skills can be taught. Thus, intelligence is malleable rather than fixed. Researchers largely agree that some improvements are possible. They disagree regarding both the degree to which they believe that such improvements can be achieved and the means by which to do so.
5. **How does intelligence continue to develop in adults?** Intelligence continues to change in adulthood. Crystallized abilities appear to increase fairly steadily. Fluid abilities sometimes decline, especially within the last 10 years before death. A number of researchers have investigated wisdom, which can be seen as an extension of intelligence. Wisdom involves knowledge of the pragmatics of life. Wise people, according to some theorists, seek a common good.
6. **How have researchers attempted to simulate intelligence using machines such as computers?** AI research is conducted on the premise that having machines simulate intelligence is both possible and valuable. The Turing Test is designed to evaluate the extent to which particular AI programs have succeeded in simulating humanlike intelligence.

   Critics of AI, however, question both the possibility and the worth of trying to get machines to simulate human intelligence. They sometimes use the "Chinese Room" problem to illustrate a distinction between simulated intelligence and true understanding. Arguments can be made to support either perspective.

THINKING ABOUT THINKING: FACTUAL, ANALYTICAL, CREATIVE, AND PRACTICAL QUESTIONS

1. Briefly summarize the key strands of AI research and name an example of a program in each strand.
2. What are some of the main reasons that intelligence tests have been devised and used?
3. In what ways is the theory of multiple intelligences different from factor-analytic theories of intelligence?

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4. What are some of the strengths and limitations of the information-processing approach to intelligence?
5. How would you design a program to improve intelligence (as you define the concept)?
6. Design an experiment that would link a physiological approach to a cognitive approach to intelligence.
7. How might any of the structural approaches to intelligence lead to practical applications?
8. Contextualists underscore the importance of viewing intelligence within a given context. What are some aspects of your social, mental, or physical context that you consider important to the expression of your intelligence?

KEY TERMS

contextualism, p. 497
culture-fair, p. 599
culture-relevant tests, p. 500
emotional intelligence, p. 482
factor analysis, p. 486
"g" factor, p. 487
intelligence, p. 481
theory of multiple intelligences, p. 501
triarchic theory of human intelligence, p. 502

Glossary

accessibility the degree to which we can gain access to the available information

ACT (adaptive control of thought) in his ACT model, John Anderson synthesized some of the features of serial information-processing models and some of the features of semantic-network models; in ACT, procedural knowledge is represented in the form of production systems; declarative knowledge is represented in the form of propositional networks

ACT-R (adaptive control of thought–rational) a model of information processing that integrates a network representation for declarative knowledge and a production-system representation for procedural knowledge

agnosia a severe deficit in the ability to perceive sensory information

algorithms sequences of operations that may be repeated over and over again and that, in theory, guarantee the solution to a problem

Alzheimer's disease a disease of older adults that causes dementia as well as progressive memory loss

amnesia severe loss of explicit memory

amygdala plays an important role in emotion, especially in anger and aggression

analog codes a form of knowledge representation that preserves the main perceptual features of whatever is being represented for the physical stimuli we observe in our environment

analysis breaking down the whole of a complex problem into manageable elements

anterograde amnesia the inability to remember events that occur after a traumatic event

aphasia an impairment of language functioning caused by damage to the brain

arousal a degree of physiological excitation, responsivity, and readiness for action, relative to a baseline

artifact categories groupings that are designed or invented by humans to serve particular purposes or functions

artificial intelligence (AI) the attempt by humans to construct systems that show intelligence and, particularly, the intelligent processing of information; intelligence in symbol-processing systems, such as computers

associationism examines how events or ideas can become associated with one another in the mind to result in a form of learning

attention the active cognitive processing of a limited amount of information from the vast amount of information available through the senses, in memory, and through cognitive processes; focus on a small subset of available stimuli

autobiographical memory refers to memory of an individual's history

automatic processes involve no conscious control

automatization the process by which a procedure changes from being highly conscious to being relatively automatic; also termed proceduralization

availability the presence of information stored in long-term memory

availability heuristic cognitive shortcut that occurs when we make judgments on the basis of how easily we can call to mind what we perceive as relevant instances of a phenomenon

axon the part of the neuron through which intraneuronal conduction occurs (via the action potential) and at the terminus of which is located the terminal buttons that release neurotransmitters

base rate refers to the prevalence of an event or characteristic within its population of events or characteristics

basic level degree of specificity of a concept that seems to be a level within a hierarchy that is preferred to other levels; sometimes termed natural level

behaviorism a theoretical outlook that psychology should focus only on the relation between observable behavior, on the one hand, and environmental events or stimuli, on the other

bilinguals people who can speak two languages

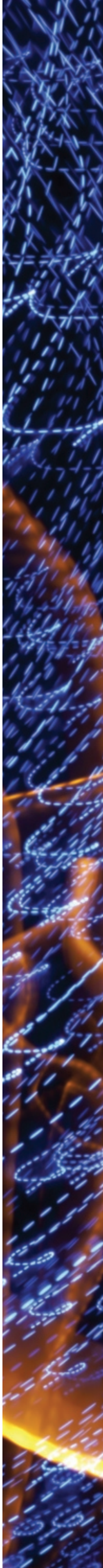
binaural presentation presenting the same two messages, or sometimes just one message, to both ears simultaneously

binocular depth cues based on the receipt of sensory information in three dimensions from both eyes

bipolar cells make dual connections forward and outward to the ganglion cells, as well as backward and inward to the third layer of retinal cells

blindsight traces of visual perceptual ability in blind areas

bottleneck theories theories proposing a bottleneck that slows down information passing through



bottom-up theories data-driven (i.e., stimulus-driven) theories

bounded rationality belief that we are rational, but within limits

brain the organ in our bodies that most directly controls our thoughts, emotions, and motivations

brainstem connects the forebrain to the spinal cord

categorical perception discontinuous categories of speech sounds

categorical syllogism a deductive argument in which the relationship among the three terms in the two premises involves categorical membership

category a concept that functions to organize or point out aspects of equivalence among other concepts based on common features or similarity to a prototype

causal inferences how people make judgments about whether something causes something else

central executive both coordinates attentional activities and governs responses

cerebellum controls bodily coordination, balance, and muscle tone, as well as some aspects of memory involving procedure-related movements; from Latin, "little brain"

cerebral cortex forms a 1- to 3-millimeter layer that wraps the surface of the brain somewhat like the bark of a tree wraps around the trunk

cerebral hemispheres the two halves of the brain

change blindness the inability to detect changes in objects or scenes that are being viewed

characteristic features qualities that describe (characterize or typify) the prototype but are not necessary for it

coarticulation occurs when phonemes or other units are produced in a way that overlaps them in time

cocktail party problem the process of tracking one conversation in the face of the distraction of other conversations

cognitive maps internal representations of our physical environment, particularly centering on spatial relationships

cognitive neuroscience the field of study linking the brain and other aspects of the nervous system to cognitive processing and, ultimately, to behavior

cognitive psychology the study of how people perceive, learn, remember, and think about information

cognitive science a cross-disciplinary field that uses ideas and methods from cognitive psychology, psychobiology, artificial intelligence, philosophy, linguistics, and anthropology

cognitivism the belief that much of human behavior can be understood in terms of how people think

communication exchange of thoughts and feelings

comprehension processes used to make sense of the text as a whole

concept an idea about something that provides a means of understanding the world

conditional reasoning occurs when the reasoner must draw a conclusion based on an if-then proposition

cones one of the two kinds of photoreceptors in the eye; less numerous, shorter, thicker, and more highly concentrated in the foveal region of the retina than in the periphery of the retina than are rods (the other type of photoreceptor); virtually nonfunctional in dim light, but highly effective in bright light and essential to color vision

confirmation bias the tendency to seek confirmation rather than disconfirmation of what we already believe

confounding variable a type of irrelevant variable that has been left uncontrolled in a study

conjunction search looking for a particular combination (conjunction: joining together) of features

connectionist models according to connectionist models, we handle very large numbers of cognitive operations at once through a network distributed across incalculable numbers of locations in the brain

connotation a word's emotional overtones, presuppositions, and other nonexplicit meanings

consciousness includes both the feeling of awareness and the content of awareness

consolidation the process of integrating new information into stored information

constructive prior experience affects how we recall things and what we actually recall from memory

constructive perception the perceiver builds (constructs) a cognitive understanding (perception) of a stimulus; he or she uses sensory information as the foundation for the structure but also uses other sources of information to build the perception

content morphemes the words that convey the bulk of the meaning of a language

context effects the influences of the surrounding environment on perception

contextualism belief that intelligence must be understood in its real-world context

contralateral from one side to another

controlled processes accessible to conscious control and even require it

convergent thinking attempt to narrow down the multiple possibilities to converge on a single best answer

converging operations the use of multiple approaches and techniques to address a problem

cooperative principle principle in conversation that holds that we seek to communicate in ways that make it easy for our listener to understand what we mean

core refers to the defining features something must have to be considered an example of a category

corpus callosum a dense aggregate of neural fibers connecting the two cerebral hemispheres

creativity the process of producing something that is both original and worthwhile

culture-fair equally appropriate and fair for members of all cultures

culture-relevant tests measure skills and knowledge that relate to the cultural experiences of the test-takers

decay occurs when simply the passage of time causes an individual to forget

decay theory asserts that information is forgotten because of the gradual disappearance, rather than displacement, of the memory trace

declarative knowledge knowledge of facts that can be stated

deductive reasoning the process of reasoning from one or more general statements regarding what is known to reach a logically certain conclusion

deductive validity logical soundness

deep structure refers to an underlying syntactic structure that links various phrase structures through the application of various transformation rules

defining feature a necessary attribute

dendrites the branch-like structures of each neuron that extend into synapses with other neurons and that receive neurochemical messages sent into synapses by other neurons

denotation the strict dictionary definition of a word

dependent variables responses that are measured and presumed to be the effect of one or more independent variables

depth the distance from a surface, usually using your own body as a reference surface when speaking in terms of depth perception

dialect a regional variety of a language distinguished by such features as vocabulary, syntax, and pronunciation

dialectic a developmental process whereby ideas evolve over time though a back-and-forth exchange of ideas

dichotic presentation presenting a different message to each ear

direct perception theory belief that the array of information in our sensory receptors, including the sensory context, is all we need to perceive anything

discourse encompasses language use at the level beyond the sentence, such as in conversation, paragraphs, stories, chapters, and entire works of literature

dishabituation change in a familiar stimulus that prompts us to start noticing the stimulus again

distracters nontarget stimuli that divert our attention away from the target stimulus

distributed practice learning in which various sessions are spaced over time

divergent thinking when one tries to generate a diverse assortment of possible alternative solutions to a problem

divided attention the prudent allocation of available attentional resources to coordinate the performance of more than one task at a time

dual-code theory belief suggesting that knowledge is represented both in images and in symbols

dual-system hypothesis suggests that two languages are represented somehow in separate systems of the mind

dyslexia difficulty in deciphering, reading, and comprehending text

ecological validity the degree to which particular findings in one environmental context may be considered relevant outside that context

electroencephalograms (EEGs) recordings of the electrical frequencies and intensities of the living brain, typically recorded over relatively long periods

elimination by aspects occurs when we eliminate alternatives by focusing on aspects of each alternative, one at a time

embodied cognition states an organism's cognition is substantially influenced by aspects of the organism's body, not just the brain; in other words, our body, not just our brain, influences the way we think, feel, and act

emotional intelligence the ability to perceive and express emotion, assimilate emotion in thought, understand and reason with emotion, and regulate emotion in the self and others

empiricist one who believes that we acquire knowledge via empirical evidence

encoding refers to how you transform a physical, sensory input into a kind of representation that can be placed into memory

encoding specificity what is recalled depends on what is encoded

episodic buffer a limited-capacity system that is capable of binding information from the subsidiary systems and from long-term memory into a unitary episodic representation

episodic memory stores personally experienced events or episodes

event-related potential an electrophysiological response to a stimulus, whether internal or external

executive attention a subfunction of attention that includes processes for monitoring and resolving conflicts that arise among internal processes

exemplars typical representatives of a category

expertise superior skills or achievement reflecting a well-developed and well-organized knowledge base

explicit memory when participants engage in conscious recollection

factor analysis a statistical method for separating a construct into a number of hypothetical factors or traits that the researchers believe form the basis of individual differences in test performance

fallacy erroneous reasoning

feature-integration theory explains the relative ease of conducting feature searches and the relative difficulty of conducting conjunction searches

feature-matching theories suggest that we attempt to match features of a pattern to features stored in memory

feature search simply scanning the environment for a particular feature or features

figure-ground what stands out from versus what recedes into the background

filter theories theories proposing a filter that blocks some of the information going through and thereby selects only a part of the total of information to pass through to the next stage

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flashbulb memory a memory of an event so powerful that the person remembers the event as vividly as if it were indelibly preserved on film

fovea a part of the eye located in the center of the retina that is largely responsible for the sharp central vision people use in such activities as reading or watching television or movies

frontal lobe associated with motor processing and higher thought processes, such as abstract reasoning

functional-equivalence hypothesis belief that although visual imagery is not identical to visual perception, it is functionally equivalent to it

functional fixedness the inability to realize that something known to have a particular use may also be used for performing other functions

functional magnetic resonance imaging (fMRI) a neuroimaging technique that uses magnetic fields to construct a detailed representation in three dimensions of levels of activity in various parts of the brain at a given moment

functionalism seeks to understand what people do and why they do it

function morphemes a morpheme that adds detail and nuance to the meaning of the content morphemes or helps the content morphemes fit the grammatical context

ganglion cells a kind of neuron usually situated near the inner surface of the retina of the eye; receive visual information from photoreceptors by way of bipolar cells and amacrine cells; send visual information from the retina to several different parts of the brain, such as the thalamus and the hypothalamus

Gestalt approach to form perception based on the notion that the whole differs from the sum of its individual parts

Gestalt psychology states that we best understand psychological phenomena when we view them as organized, structured wholes

"g" factor general ability

grammar the study of language in terms of noticing regular patterns

habituation involves our becoming accustomed to a stimulus so that we gradually pay less and less attention to it

heuristics informal, intuitive, speculative strategies that sometimes lead to an effective solution and sometimes do not

hindsight bias when we look at a situation retrospectively, we believe we easily can see all the signs and events leading up to a particular outcome

hippocampus plays an essential role in memory formation

hypermnesia a process of producing retrieval of memories that seem to have been forgotten

hypothalamus regulates behavior related to species survival: fighting, feeding, fleeing, and mating; also active in regulating emotions and reactions to stress

hypotheses tentative proposals regarding expected empirical consequences of the theory

hypothesis testing a view of language acquisition that asserts that children acquire language by mentally forming tentative hypotheses regarding language, based on their inherited facility for language acquisition and then testing these hypotheses in the environment

hypothetical constructs concepts that are not themselves directly measurable or observable but that serve as mental models for understanding how a psychological phenomenon works

iconic store a discrete visual sensory register that holds information for very short periods

ill-structured problems problems that lack well-defined paths to solution

illusory correlation occurs when we tend to see particular events or particular attributes and categories as going together because we are predisposed to do so

imagery the mental representation of things that are not currently being sensed by the sense organs

implicit memory when we recollect something but are not consciously aware that we are trying to do so

inattentional blindness refers to inability to see an object for failure to attend to it, even if it is in plain sight; it is a lack of attention that is not associated with any intrinsic visual deficits; in inattentional blindness, an object that an individual fails to recognize often is in plain sight but nevertheless is not perceived

incubation putting the problem aside for a while without consciously thinking about it

independent variables variables that are varied or purposefully manipulated and that affect one or more dependent variables

inductive reasoning the process of reasoning from specific facts or observations to reach a likely conclusion that may explain the facts

infantile amnesia the inability to recall events that happened when we were very young

insight a distinctive and sometimes seemingly sudden understanding of a problem or of a strategy that aids in solving the problem

intelligence the capacity to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the surrounding environment

interference occurs when competing information causes an individual to forget something

interference theory refers to the view that forgetting occurs because recall of certain words interferes with recall of other words

introspection looking inward at pieces of information passing through consciousness

ipsilateral on the same side

isomorphic the formal structure is the same, and only the content differs

jargon specialized vocabulary commonly used within a group, such as a profession or a trade

judgment and decision making used to select from among choices or to evaluate opportunities

knowledge representation the form for what you know in your mind about things, ideas, events, and so on that exist outside your mind

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Korsakoff's syndrome produces loss of memory function

language the use of an organized means of combining words to communicate

law of Prägnanz tendency to perceive any given visual array in a way that most simply organizes the disparate elements into a stable and coherent form

levels-of-processing framework postulates that memory does not comprise three or even any specific number of separate stores but rather varies along a continuous dimension in terms of depth of encoding

lexical access the identification of a word that allows us to gain access to the meaning of the word from memory

lexical processes used to identify letters and words

lexicon the entire set of morphemes in a given language or in a given person's linguistic repertoire

limbic system important to emotion, motivation, memory, and learning

linguistic relativity the assertion that speakers of different languages have differing cognitive systems and that these different cognitive systems influence the ways in which people speaking the various languages think about the world

linguistic universals characteristic patterns across all languages of various cultures

lobes divide the cerebral hemispheres and cortex into four parts

localization of function refers to the specific areas of the brain that control specific skills or behaviors

long-term store very large capacity, capable of storing information for very long periods, perhaps even indefinitely

magnetic resonance imaging (MRI) scan a technique for revealing high-resolution images of the structure of the living brain by computing and analyzing magnetic changes in the energy of the orbits of nuclear particles in the molecules of the body

magnetoencephalography (MEG) an imaging technique that measures the magnetic fields generated by electrical activity in the brain by highly sensitive measuring devices

massed practice learning in which sessions are crammed together in a very short space of time

medulla oblongata brain structure that controls heart activity and largely controls breathing, swallowing, and digestion

memory the means by which we retain and draw on our past experiences to use this information in the present

mental model a knowledge structure that individuals construct to understand and explain their experiences; an internal representation of information that corresponds analogously with whatever is being represented

mental rotation involves rotationally transforming an object's visual mental image

mental set a frame of mind involving an existing model for representing a problem, a problem context, or a procedure for problem solving

metacognition our understanding and control of our cognition; our ability to think about and control our own processes of thought and ways of enhancing our thinking

metamemory strategies involve reflecting on our own memory processes with a view to improving our memory

metaphor two nouns juxtaposed in a way that positively asserts their similarities, while not disconfirming their dissimilarities

mnemonic devices specific techniques to help you memorize lists of words

mnemonist someone who demonstrates extraordinarily keen memory ability, usually based on the use of special techniques for memory enhancement

modular divided into discrete modules that operate more or less independently of each other

monocular depth cues can be represented in just two dimensions and observed with just one eye

monolinguals people who can speak only one language

morpheme the smallest unit that denotes meaning within a particular language

multimode theory proposes that attention is flexible; selection of one message over another message can be made at any of various different points in the course of information processing

myelin a fatty substance coating the axons of some neurons that facilitates the speed and accuracy of neuronal communication

natural categories groupings that occur naturally in the world

negative transfer occurs when solving an earlier problem makes it harder to solve a later one

nervous system the organized network of cells (neurons) through which an individual receives information from the environment, processes that information, and then interacts with the environment

networks a web of relationships (e.g., category membership, attribution) between nodes

neurons individual nerve cells

neurotransmitters chemical messengers used for interneuronal communication

nodes the elements of a network

nodes of Ranvier gaps in the myelin coating of myelinated axons

nominal kind the arbitrary assignment of a label to an entity that meets a certain set of prespecified conditions

noun phrase syntactic structure that contains at least one noun (often, the subject of the sentence) and includes all the relevant descriptors of the noun

object-centered representation the individual stores a representation of the object, independent of its appearance to the viewer

occipital lobe associated with visual processing, the primary motor cortex, which specializes in the planning, control, and execution of movement, particularly of movement involving any kind of delayed response

optic ataxia impaired visual control of the arm in reaching out to a visual target

optic nerve the nerve that transmits information from the retina to the brain

overconfidence an individual's overvaluation of her or his own skills, knowledge, or judgment

overregularization occurs when individuals apply the general rules of language to the exceptional cases that vary from the norm

parallel distributed processing (PDP) models or connectionist models the handling of very large numbers of cognitive operations at once through a network distributed across incalculable numbers of locations in the brain

parallel processing occurs when multiple operations are executed all at once

parietal lobe associated with somatosensory processing

perception the set of processes by which we recognize, organize, and make sense of the sensations we receive from environmental stimuli

perceptual constancy occurs when our perception of an object remains the same even when our proximal sensation of the distal object changes

phoneme is the smallest unit of speech sound that can be used to distinguish one utterance in a given language from another

phonemic-restoration effect sounds that are missing from a speech signal are constructed by the brain so it seems to the listener that he actually heard the missing sound

phonological loop briefly holds inner speech for verbal comprehension and for acoustic rehearsal

photopigments chemical substances that absorb light, thereby starting the complex transduction process that transforms physical electromagnetic energy into an electrochemical neural impulse; rods and cones contain different types of photopigments; different types of photopigments absorb differing amounts of light and may detect different hues

photoreceptors the third layer of the retina contains the photoreceptors, which transduce light energy into electrochemical energy

phrase-structure grammar syntactical analysis of the structure of phrases as they are used

pons serves as a kind of relay station because it contains neural fibers that pass signals from one part of the brain to another

positive transfer occurs when the solution of an earlier problem makes it easier to solve a new problem

positron emission tomography (PET) scans measure increases in glucose consumption in active brain areas during particular kinds of information processing

pragmatic reasoning schemas general organizing principles or rules related to particular kinds of goals, such as permissions, obligations, or causations

pragmatics the study of how people use language

pragmatists ones who believe that knowledge is validated by its usefulness

premises propositions about which arguments are made

primacy effect refers to superior recall of words at and near the beginning of a list

primary motor cortex region of the cerebral cortex that is chiefly responsible for directing the movements of all muscles

primary somatosensory cortex receives information from the senses about pressure, texture, temperature, and pain

prime a node that activates a connected node; this activation is known as the priming effect

priming the facilitation of one's ability to utilize missing information; occurs when recognition of certain stimuli is affected by prior presentation of the same or similar stimuli

priming effect the resulting activation of the node

proactive interference occurs when the interfering material occurs before, rather than after, learning of the to-be-remembered material

problem solving an effort to overcome obstacles obstructing the path to a solution

problem-solving cycle includes problem identification, problem definition, strategy formulation, organization of information, allocation of resources, monitoring, and evaluation

problem space the universe of all possible actions that can be applied to solving a problem, given any constraints that apply to the solution of the problem

procedural knowledge knowledge of procedures that can be implemented

production the generation and output of a procedure

production system an ordered set of productions in which execution starts at the top of a list of productions, continues until a condition is satisfied, and then returns to the top of the list to start anew

productive thinking involves insights that go beyond the bounds of existing associations

proposition basically an assertion, which may be either true or false

propositional theory belief suggesting that knowledge is represented only in underlying propositions, not in the form of images or of words and other symbols

prototype a sort of average of a class of related objects or patterns, which integrates all the most typical (most frequently observed) features of the class

prototype theory suggests that categories are formed on the basis of a (prototypical, or averaged) model of the category

psycholinguistics the psychology of our language as it interacts with the human mind

rationalist one who believes that the route to knowledge is through logical analysis

reasoning the process of drawing conclusions from principles and from evidence

recall to produce a fact, a word, or other item from memory

recency effect refers to superior recall of words at and near the end of a list

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recognition to select or otherwise identify an item as being one that you learned previously

recognition-by-components (RBC) theory the belief that we quickly recognize objects by observing the edges of objects and then decomposing the objects into geons

reconstructive involving the use of various strategies (e.g., searching for cues, drawing inferences) for retrieving the original memory traces of our experiences and then rebuilding the original experiences as a basis for retrieval

referent the thing or concept in the real world that a word refers to

rehearsal the repeated recitation of an item

representativeness occurs when we judge the probability of an uncertain event according to (1) its obvious similarity to or representation of the population from which it is derived and (2) the degree to which it reflects the salient features of the process by which it is generated (such as randomness)

reticular activating system (RAS) a network of neurons essential to the regulation of consciousness (sleep, wakefulness, arousal, and even attention to some extent and to such vital functions as heartbeat and breathing); also called reticular formation

retina a network of neurons extending over most of the back (posterior) surface of the interior of the eye; the retina is where electromagnetic light energy is transduced—that is, converted—into neural electrochemical impulses

retrieval (memory) refers to how you gain access to information stored in memory

retroactive interference caused by activity occurring after we learn something but before we are asked to recall that thing; also called retroactive inhibition

retrograde amnesia occurs when individuals lose their purposeful memory for events before whatever trauma induces memory loss

rods light-sensitive photoreceptors in the retina of the eye that provide peripheral vision and the ability to see objects at night or in dim light; rods are not color sensitive

satisficing occurs when we consider options one by one, and then we select an option as soon as we find one that is satisfactory or just good enough to meet our minimum level of acceptability

schemas mental frameworks for representing knowledge that encompass an array of interrelated concepts in a meaningful organization

script a structure that describes appropriate sequences of events in a particular context

search refers to a scan of the environment for particular features—actively looking for something when you are not sure where it will appear

selective attention choosing to attend to some stimuli and to ignore others

selective-combination insight involves taking selectively encoded and compared snippets of relevant information and combining that information in a novel, productive way

selective-comparison insight involves novel perceptions of how new information relates to old information

selective-encoding insight involves distinguishing relevant from irrelevant information

semantic memory stores general world knowledge

semantic network a web of interconnected elements of meaning

semantics the study of meaning in a language

sensory store capable of storing relatively limited amounts of information for very brief periods

septum involved in anger and fear

serial-position curve represents the probability of recall of a given word, given its serial position (order of presentation) in a list

serial processing means by which information is handled through a linear sequence of operations, one operation at a time

short-term store capable of storing information for somewhat longer periods but also of relatively limited capacity

signal a target stimulus

signal detection the detection of the appearance of a particular stimulus

signal-detection theory (SDT) a theory of how we detect stimuli that involves four possible outcomes of the presence or absence of a stimulus and our detection or nondetection of a stimulus

simile introduces the word *like* or *as* into a comparison between items

single-system hypothesis suggests that two languages are represented in just one system

slips of the tongue inadvertent linguistic errors in what we say

soma the cell body of a neuron that is the part of the neuron essential to the life and reproduction of the cell

spacing effect refers to the fact that long-term recall is best when the material is learned over a longer period of time

spatial cognition refers to the acquisition, organization, and use of knowledge about objects and actions in two- and three-dimensional space

split-brain patients people who have undergone operations severing the corpus callosum

spreading activation excitation that fans out along a set of nodes within a given network

statistical significance indicates the likelihood that a given set of results would be obtained if only chance factors were in operation

stereotypes beliefs that members of a social group tend more or less uniformly to have particular types of characteristics

storage (memory) refers to how you retain encoded information in memory

Stroop effect demonstrates the psychological difficulty in selectively attending to the color of the ink and trying to ignore the word that is printed with the ink of that color

structuralism seeks to understand the structure (configuration of elements) of the mind and its perceptions by analyzing those perceptions into their constituent components

subjective probability a calculation based on the individual's estimates of likelihood, rather than on objective statistical computations

subjective utility a calculation based on the individual's judged weightings of utility (value), rather than on objective criteria

surface structure a level of syntactic analysis that involves the specific syntactical sequence of words in a sentence and any of the various phrase structures that may result

syllogisms deductive arguments that involve drawing conclusions from two premises

symbolic representation meaning that the relationship between the word and what it represents is simply arbitrary

synapse a small gap between neurons that serves as a point of contact between the terminal buttons of one or more neurons and the dendrites of one or more other neurons

syntax refers to the way in which users of a particular language put words together to form sentences

synthesis putting together various elements to arrange them into something useful

templates highly detailed models for patterns we potentially might recognize

temporal lobe associated with auditory processing

terminal buttons knobs at the end of each branch of an axon; each button may release a chemical neurotransmitter as a result of an action potential

thalamus relays incoming sensory information through groups of neurons that project to the appropriate region in the cortex

thematic roles ways in which items can be used in the context of communication

theory an organized body of general explanatory principles regarding a phenomenon

theory-based view of meaning holds that people understand and categorize concepts in terms of implicit theories, or general ideas they have regarding those concepts

theory of multiple intelligences belief that intelligence is made up of multiple independent constructs, not just a single, unitary construct

tip-of-the-tongue phenomenon experience of trying to remember something that is known to be stored in memory but that cannot readily be retrieved

top-down theories driven by high-level cognitive processes, existing knowledge, and prior expectations

transcranial magnetic stimulation (TMS) technique that temporarily disrupts the normal activity of the brain in a limited area by placing a coil on a person's head and then allowing an electrical current to pass though it; the current generates a magnetic field and this field disrupts the small area (usually no more than a cubic centimeter) beneath it; the researcher can then look at cognitive functioning when the particular area is disrupted

transfer any carryover of knowledge or skills from one problem situation to another

transformational grammar involves the study of transformational rules that guide the ways in which underlying propositions can be rearranged to form various phrase structures

transparency occurs when people see analogies where they do not exist because of similarity of content

triarchic theory of human intelligence belief that intelligence includes three aspects dealing with the relation of intelligence (1) to the internal world of the person, (2) to experience, and (3) to the external world

verbal comprehension the receptive ability to comprehend written and spoken linguistic input, such as words, sentences, and paragraphs

verbal fluency the expressive ability to produce linguistic output

verb phrase syntactic structure that contains at least one verb and whatever the verb acts on, if anything

viewer-centered representation an individual stores the way the object looks to him or her

vigilance refers to a person's ability to attend to a field of stimulation over a prolonged period, during which the person seeks to detect the appearance of a particular target stimulus of interest

visual cortex the part of the brain that processes visual information

visuospatial sketchpad briefly holds some visual images

well-structured problems problems that have well-defined paths to solution

word-superiority effect letters are read more easily when they are embedded in words than when they are presented either in isolation or with letters that do not form words

working memory holds only the most recently activated portion of long-term memory, and it moves these activated elements into and out of brief, temporary memory storage

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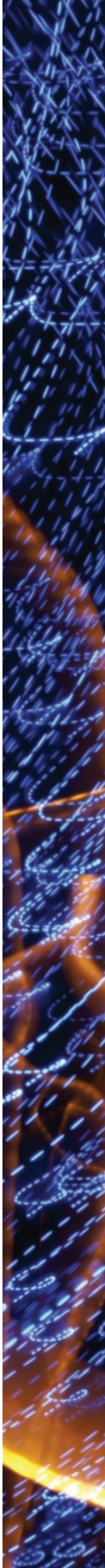

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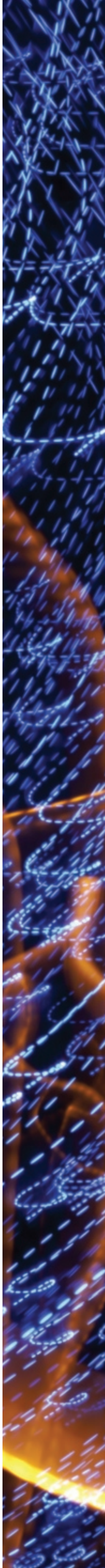

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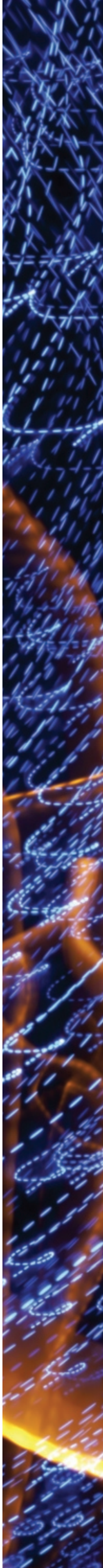

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